THE UNIVERSITY OF ALBERTA

AN OXIDATION - REDUCTION POTENTIAL STUDY

OF ACTIVATED SLUDGE PROCESS MODIFICATIONS

BY

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A THESIS

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ABSTRACT

An oxidation - reduction potential study, focussed on secondary aeration tank operations, was performed at the Edmonton Sewage Treatment Plant during March and April, 1973. The method of biological treatment employed at the plant was a version of the activated sludge process which resembled the contact stabilization process as well as other modifications of the conventional process.

The main study objective was to determine if ORP measurements could indicate the degree of treatment progression in the aeration tanks and, in pursuing this objective, it also was hoped that better secondary operating methods might be discovered.

A literature review of the theoretical basis for ORP measurements indicated that they should be useful in providing information on the state of oxidation of sewage, according to a fundamental electronic concept in which the tendency for electron transfer forms the basis. It was generally agreed that ORP in aeration tanks should be maintained about +100 mv. (E_h) to avoid lowering the rate of oxidative destruction of organic material by microorganisms.

In attempting to accomplish the study objective, the author took numerous ORP profiles of the aeration tanks and compared them with data on DO profiles and plant performance. One of the aeration

tanks was investigated under different operating procedures which involved change in such variables as points of sewage addition, hydraulic loading rate, aeration rate, and suspended solids concentrations. ORP measurements on various grab samples, having no atmospheric contact, were made over a period of time and the results compared with those in the literature.

A wide variety of ORP profiles were obtained, with potentials varying from less than +100 mv. to more than +400 mv. (E_h). At values above +150 mv. no noticeable effect of ORP on secondary treatment efficiency was observed, and at values around +100 mv. substantially worse treatment was obtained. No unique relationship was found between ORP and DO; however, the two variables did increase and decrease simultaneously for a given profile. Generally, the change in DO was large compared to the change in ORP when the ORP was above +350 mv. and small compared to the change in ORP when below +300 mv. ORP readings on grab samples over a time period were found to decrease at various rates, depending upon sampling location and secondary operating procedure, to values as low as -200 mv. Poor comparison with ORP reduction curves in the literature was obtained.

The study objective was accomplished by showing that ORP measurements indicate only if unsatisfactory aeration exists in aeration tanks. Better operating procedures were discovered as a result of the study. Excessive return sludge aeration time and low RSSS and MLSS appeared to be the main drawbacks of the normal operating procedure for the tanks. Recommendations for further study focussed on monitoring ORP for the purpose of aeration control in secondary aeration tanks.

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LIST OF SYMBOLS

BOD	biochemical oxygen demand
DO	dissolved oxygen
e	electron
emf	electromotive force or electrode potential
E	electrode potential
E_c	electrode potential with respect to the calomel electrode
E_h	electrode potential with respect to the hydrogen electrode
E_o	electrode potential of a chemical system at 25°C with equal concentrations of the oxidized and reduced forms, with respect to the hydrogen electrode
F	Faraday's Constant
IGD	imperial gallons per day
mg./l.	milligrams per liter
mv.	millivolts
MCFD	million cubic feet per day
MIGD	million imperial gallons per day
MLSS	mixed liquor suspended solids
n	number of electrons
O-R	oxidation - reduction
ORP	oxidation - reduction potential
Ox	oxidized form of a chemical species
Q	flow rate
R	universal gas constant
Red	reduced form of a chemical species
RSSS	return sludge suspended solids
s	standard deviation
SS	suspended solids
T	temperature

CHAPTER I

INTRODUCTION

1.1 Area of Investigation

An oxidation - reduction potential study of secondary treatment operations at the Edmonton Sewage Treatment Plant was performed during March and April, 1973. The main objective of the study was to determine if ORP measurments (or O-R potentials) could provide a good indication of satisfactory secondary aeration tank operation. Also, it was anticipated that a related benefit of the study might be the discovery of more efficient and/or more economical plant operating methods. The normal method of secondary treatment was contact stabilization, a version of the activated sludge process.

From a theoretical standpoint, aeration tank conditions can be evaluated with ORP measurements. These reflect the state of oxidation of a system according to a fundamental electronic concept in which the tendency for electron transfer forms the basis. This concept is necessary because many biological oxidations and reductions do not occur in the presence of oxygen, but do involve an electron loss or gain. The ORP of a system depends upon many factors, the most important of which is the ratio of concentrations of the oxidized to the reduced forms of the system's components. Thus, in biological systems,

ORP determinations should give invaluable information regarding the oxidation state of such systems and the progression of biological processes.

In an attempt to accomplish the main study objective, numberous ORP profiles were run on the aeration tanks and some dissolved oxygen profiles were taken for comparison. Also, some measurements of the change in ORP with time were made on grab samples having no contact with the atmosphere. Measurements were performed on all of the five aeration tanks under normal operation and on one of the tanks after incorporating various operational changes.

1.2 Limitations of Research

1.2.1 Control of Variables

It was impossible to perform a well controlled ORP study of various operational changes because of many uncontrollable variables. Influent characteristics and flow rates were subject to wide hourly, daily, and monthly changes. Also, plant operation varied widely depending upon the effects of the above factors on treatment progression.

Plant operation, especially aeration rates, varied widely. This depended upon the loading conditions and, to some extent, the reaction of plant operators to changing aeration tank dissolved oxygen concentrations which were constantly monitored.

To cope with the large ranges of variables encountered, only one aeration tank was examined under various operating conditions, while the others were used as controls under normal conditions. A

process change could then be roughly evaluated by comparison with normal processes in other aeration tanks over the same time interval.

1.2.2 Accuracy of Data

The accuracy of some of the data presented in this thesis was somewhat in doubt. The problems involved in overcoming this uncertainty were considered too extensive to be tackled at the time of the study.

Data having questionable accuracy was that on various aspects of plant loading and operation. Flow rate measurements for secondary influent, return sludge, waste sludge, and diffused air were made by plant personnel with instruments that had not been calibrated recently before the study. The relative distribution of secondary influent to each aeration tank was also uncertain since no measuring devices for the individual tank flows were available. Aeration data was particularly doubtful because no automatic recording device was available and readings by plant personnel were taken only at one time each day.

1.2.3 Measurements by Others

Because of the great amount of data required for the study, good use was made of the results of laboratory tests and routine measurements taken by plant staff. Also, DO profiles by the staff were used to compare with ORP profiles by the author. Long response times associated with some ORP measurements made it impractical to perform the two types of profiles at coinciding times. Since the aeration tank conditions may have changed significantly during such periods, some

inaccuracies could have resulted in comparing DO and ORP profiles.

1.3 Organization of Thesis

The following chapters cover a literature review of OR potentials, a description of the Edmonton Sewage Treatment Plant, an explanation of the study procedure, an analysis of the results, and formulation of conclusions and recommendations.

In the literature review of OR potentials in CHAPTER II almost all aspects of the measurements are presented in a general way. More specific applications relating to aeration tanks are described at the end of the chapter.

A description of the Edmonton Sewage Treatment Plant is given in CHAPTER III along with some theory on the activated sludge process. This is presented to facilitate interpretation of the ORP results and place them in their proper perspective.

CHAPTERS IV, V and VI deal with the study: the procedure, the results, and the conclusions. Also, at the end of CHAPTER VI some recommendations are made for further study.

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1 General

A number of researchers have investigated the various uses of oxidation - reduction potentials (ORP or O-R potentials) in sewage treatment processes. While the list of significant uses is impressive, application of ORP measurements in the Sanitary Engineering field has been somewhat limited. Perhaps one of the main reasons for the poor acceptance of O-R potentials stems from confusion regarding their meaning. Also to be considered is the fact that sewage treatment plant operators have other dependable, proven monitoring equipment at their fingertips while the dependability of ORP measuring equipment might be questioned. Nevertheless, the literature in most cases suggests that ORP measurements could provide additional, significant information on sewage plant operations.

In the following literature review, an attempt is made first to clarify the theoretical background or basis of O-R potentials. The electrodes used in the measurement then are described in detail as well as the methods of measurement. Finally, results of ORP measurements at various sewage treatment plants are presented.

2.2 Theory of O-R Potentials

2.2.1 Definition of Oxidation and Reduction

Hewitt (1950) stated that "biological systems cannot be expected to yield to study unless there is available a means of measuring their oxidizing or reducing properties . . . ." The ORP measurement provides this means by describing the state of oxidation of sewage or other systems according to the fundamental electronic concept of matter. Oxidation of a substance occurs when it loses one or more electrons; reduction occurs when it gains one or more electrons. Also, for every biological or chemical oxidation there must be an accompanying reduction. That is, when one compound is oxidized, it loses electrons to another compound which becomes reduced.

One special type of oxidation-reduction reaction involves the removal of hydrogen ions (H^+) from a compound (dehydrogenation). This reaction, which is common in biological systems, also involves a loss of electrons from the dehydrogenated compound. Therefore, the reaction is an oxidation. Conversely, if the reaction proceeded in the opposite direction, it would be a reduction or hydrogenation.

Other commonly used terms cited in the literature include oxidizing agent or oxidant, and reducing agent or reductant. An oxidant is capable of bringing about the oxidation of another compound by accepting electrons. The reverse is true for a reductant.

Synonyms for the term oxidation - reduction potential include reduction potential, redox potential, and electrode potential (Hewitt,

1950). ORP and electrode potential appear to be the most commonly used terms in the literature. However, some confusion exists regarding the intended meanings as is explained in Section 2.2.5.

2.2.2 Biological Considerations

Because sewage treatment systems involve living organisms as well as chemical compounds, an explanation of ORP reactions from a biological point of view is necessary. All organisms require energy for growth and reproduction. The ability to utilize and transform energy is one of the most fundamental properties of living organisms. Oxidation - reduction reactions provide the means by which microorganisms utilize chemical energy from chemical substances, both organic and inorganic. The energy contained in a compound depends upon its oxidation state. The more reduced forms of a compound contain greater quantities of energy then the more oxidized forms (Brock, 1970).

The use of chemical energy by microorganisms ususally requires the presence of an external electron acceptor. Only in fermentation reactions can microorganisms use energy without this aid because portions of the organic compounds are oxidized while other portions are reduced.

A requirement in all biochemical energy transformations is the presence of suitable enzymes. These are proteins which catalyze biological conversions and may function with various cofactors which act as electron acceptors or donors.

Biological oxidation of an energy source with an external

electron acceptor is called respiration. In aerobic systems, gaseous oxygen (O_2) is most important in this regard; however in anaerobic systems, other compounds may perform this function. Common examples are NO_3^-, $SO_4^=$, and CO_2 which are ultimately reduced to N_2, H_2S, and CH_4 respectively.

2.2.3 Nernst Equation

The driving force for a chemical reaction depends upon the relative concentrations of the reactants and products. For a simple system containing the oxidized and reduced forms of a chemical species, a general equation may be written as follows:

$$Ox + ne \rightleftharpoons Red$$

Where Ox is the oxidized form of the chemical species

Red is the reduced form of the chemical species

e represents an electron

n is the number of electrons.

The above equation must be balanced with regard to charges as well as species. For example, the chemical species, iron, often occurs as ferrous iron or ferric iron. Ferric iron may be reduced to ferrous iron by gaining an electron in the half-reactions:

$$Fe^{+++} + e \rightleftharpoons Fe^{++}$$

The driving force (or electromotive force) for a reaction can be formulated in terms of the well known Nernst equation, derivations

of which appear in the literature (Hewitt, 1950; Fischer and Peters, 1968):

$$E_h = E_o + \frac{RT}{nF} \ln \frac{(Ox)}{(Red)}$$

Where E_h = Electromotive force referred to the normal hydrogen electrode.

E_o = Constant for the particular system at 25°C. In the literature, values of E_o are tabulated for numerous half-reactions.

R = Gas constant = 8.315 $\frac{\text{volt-coulombs}}{\text{gram mole - K}^o}$

T = Absolute temperature = 298°K

n = Number of electrons which participate in the oxidation - reduction reaction or the number of gram equivalent weights per gram mole.

F = Faraday's constant = 96,500 $\frac{\text{coulombs}}{\text{gram equivalent weight}}$

() Indicates concentration.

Substituting into the above equation and using common logarithms instead of natural logarithms,

$$E_h = E_o + \frac{0.059}{n} \log \frac{(Ox)}{(Red)}$$

For the ferrous-ferric half-reaction, E_o = +0.771 volts. Therefore, different electromotive forces, shown in TABLE I, would be observed for various degrees of oxidation at 25°C.

TABLE I: THEORETICAL O-R POTENTIALS FOR Fe^{+++} - Fe^{++} SYSTEM

% Fe^{+++} (or % Oxidized)	Fe^{+++} / Fe^{++}	E_h (Volts)
1	1/99 = .0101	-1.225
25	25/75 = .333	+0.294
50	50/50 = 1.000	0.771
75	75/25 = 3.000	1.248
99	99/1 = 99.000	2.767

From the above table, two main observations are apparent. First, when the system is 50% oxidized, $E_h = E_o$. Secondly, as the Fe^{+++} - Fe^{++} system becomes more oxidized, E_h increases and as the system becomes more reduced, E_h decreases.

The Nernst equation applies only if the conditions of thermodynamic equilibrium exist; that is, constant pressure, constant temperature, and reversibility.

Biological systems are extremely complex since they are composed of proliferations of living and non-living organic matter as well as various inorganic and organic compounds and dissolved gases. Biological conversions involve a multitude of oxidation - reduction reactions. While the conditions of constant pressure, constant temperature, and reversibility are not satisfied in biological systems; O-R potentials are nevertheless an indication of the state of health of such systems (Eckenfelder and Hood, 1951; Nussberger, 1953; and Hood and Rolich, 1959). The importance of O-R potentials during various

stages of sewage treatment thus becomes evident.

2.2.4 Significance of ORP

From the foregoing description of the Nernst equation, it can be seen that O-R potentials are not quantitative measurements. They furnish no information regarding the quantity of oxidants or reductants in a system. This can usually be determined by performing a titration which indicates the degree to which the system resists changes in ORP (poising capacity).

Despite the fact that O-R potentials are only qualitative measurements and give no indication of a system's poising capacity, they can still furnish useful information. Two simple analogies may help to demonstrate this point. First, temperature measurements furnish no information regarding the heat capacity of a body. Secondly, pH measurements furnish no information regarding the buffering capacity of a system. This in no way detracts from the importance of temperature and pH in addition to heat capacity and buffering capacity, respectively.

The value of ORP measurements in sewage treatment processes can be assessed by looking at past experiences and possible uses. Unfortunately, in evaluating the test much weight must be placed upon the possible uses because of some unproven, irreproducible results which have been presented in the literature.

The following uses for ORP measurements of sewage have been suggested (Moore et al., 1942; Eliassen, 1945; Hood and Rolich, 1959; Eckenfelder and O'Connor, 1961; Dirasian, 1968):

1. Detection of septic conditions which lead to sulphide production in sewer, pumping, and related facilities.
2. Detection of industrial wastes and toxic conditions.
3. Establishment of proper sludge pumping schedules.
4. Detection of stagnation in primary tanks and control of chlorination to avoid septicity.
5. Determination and control conditions in activated sludge aeration tanks.
6. Detection of excessive sludge blanket in settling tanks.
7. Determination and control of conditions in sludge digestion tanks.
8. Examination of influents and effluents.

Various practical problems may limit the usefulness of some ORP measurements. For example, Henry (1973) found that "the (Miami) Plant installation of the instrument available at the time (1958) required so much attention that it was discontinued." Only ORP readings on grab samples are now taken at Miami.

2.2.5 Measurement of ORP

ORP indicates the tendency of electrons to escape from solution and consequently the state of oxidation of that solution. In order to measure this potential for electron escape an unattackable electrode, acting merely as an inert conductor of electrons, is required. It is

necessary to complete the electric circuit with a constant voltage reference electrode, which forms one half-cell while the solution undergoing measurement forms the other.

A number of unattackable, measuring electrodes has been investigated. Hewitt (1950) described and compared the merits of five of these electrodes: platinum, gold, irridium, tungsten, and graphite. Other electrodes mentioned in the literature include mercury, rhodium and palladium (Dirasian, 1968). Hewitt concluded that platinum appeared to be the most suitable. Other investigators have supported his contention (Dirasian, 1968; Natarajan and Iwasaki, 1970), although good results have also been obtained using gold electrodes (Okey et al., 1946). The deciding factor for the use of platinum instead of gold electrodes appears to be the ease with which the former can be constructed.

In an ORP determination, the voltage measured is the difference between the potential developed at the inert and at the reference electrode. Various reference electrodes have been employed. If the standard hydrogen gas electrode is used, the true ORP (E_h) is measured directly. If a calomel or silver-silver chloride electrode is used, it is necessary to employ a "correction factor" according to the following equation (Kehoe and Jones, 1961):

$$E_h = E + \text{voltage of reference electrode}$$

Where E_h = the potential with respect to the hydrogen electrode at all temperatures.

E = the observed voltage with the reference electrode being used.

Potential of standard calomel reference electrode (with saturated KCl at 25° C) = 244 mv.

Potential of silver-silver chloride reference electrode (with 4M KCl at 25°C) = 199 mv.

Potential of standard hydrogen electrode = 0 mv.

The most frequent combination of electrodes used is the platinum measuring electrode and the saturated calomel reference electrode. The measured potential in this case is termed E_c, the potential relative to the calomel electrode. Substituting into the equation for the correction factor, the following simple relationship is obtained:

$E_h = E_c + 244$ mv., where E_c is expressed in millivolts.

Dirasion (1968) advocated that redox measurements of sewage not be called ORP measurements. His contention was that biological systems do not follow the thermodynamic Nernst equation; consequently, the potential developed should be referred to as "Electrode Potential" rather than "Oxidation - Reduction Potential." Since the measurement was most often made with the platinum measuring electrode in conjunction with the saturated calomel reference electrode, Dirasion further limited his meaning of "Electrode Potentials" to those potentials measured with these electrodes. Values of Electrode Potential would then be expressed as E_c, not E_h.

It is necessary to point out that Dirasian's meaning for the term, "Electrode Potential," conflicts with the meaning associated with

it by some other workers in the area. Hewitt (1950), for one, extensively used the term to mean E_h. In addition to the problem of terminology, some confusion exists in the literature since O-R potentials are often expressed as both E_h and E_c. Sometimes the authors have even failed to mention to which electrode the potentials are referred. In such cases it appears to be moderately safe to assume that the values be taken as E_h.

In the actual measurement of ORP, the electromotive force (emf) of a solution is most reliably obtained with the use of a high impedance potentiometer. A potentiometric measurement consists of balancing a known variable emf against the emf of the solution so that practically no current flows through the system. Current detection in the order of 10^{-10} amperes can be accomplished using a galvanometer. pH meters, in fact, are sophisticated potentiometers. Balancing of the unknown and variable known emf's is accomplished quickly and automatically by these instruments. A diagram of a simple potentiometer is shown in FIGURE 1.

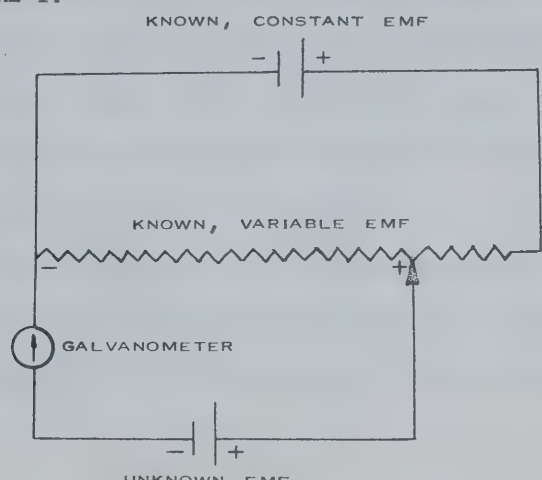


FIGURE 1: SIMPLE POTENTIOMETER

"The need for a careful procedure (in the measurement of ORP) is emphasized by the nature of sewage itself" (Henry, Aug. 1960). Measurements are best made in place, and not on grap samples for a number of reasons.

1. The sample must be representative.
2. No air may be added to the sewage in the measurement as this would increase the ORP.
3. Settling must be prevented and stirring should not cause strands of anaerobic solids to drape around the electrode as this would give readings too low.
4. The ORP of a standing sample decreases with time; whereas in a steady state treatment process, the ORP remains relatively constant.

General causes of error in the measurement of ORP are attributed to various factors. Electrodes produce completely meaningless results if the glass is cracked and contact of sewage with conductors other than platinum is established. Poor sealing of the platinum wire in glass or faulty insulation around the lead wire (made of copper) also results in the same thing. Moisture within the glass tube may indicate this type of failure. Henry (Aug. 1960) found that moisture within the pH meter case was the most prominent source of error. This problem was solved by storing the meter in a heated cabinet at 95°F to 100°F. Other sources of error included grounding of the electrode leads to the instrument, grounding of the pH meter case, and loose connections.

2.2.6 Sign Conventions

"To understand and properly interpret the equations and handbook data on this subject, it is necessary to appreciate the rather confusing sign conventions that exist" (Kehoe and Jones, 1961). Two systems in common use are the American Convention and the European Convention. In the American Convention the sign of the potential is the true polarity of the solution surrounding the measuring electrode. However, meters are not aware of this polarity but only that of the electrode. Thus, most millivolt meters read out in signs according to the European Convention which is based on the signs of the electrodes. ORP determinations of sewage have been reported strictly in the latter manner. Consequently, the more effective the oxidant, the more positive is its potential; the more effective the reductant, the more negative is its potential.

2.3 The Platinum Electrode

As mentioned previously, ORP measurements of sewage are most frequently performed with the platinum measuring electrode. Discussion of measuring electrodes in this section is therefore limited to this electrode.

2.3.1 Construction of Platinum Electrodes

Some workers in the area have preferred using "homemade" electrodes rather than commercial electrodes (Henry, Aug. 1960; Dirasian, 1968). Commercial electrodes have been found to give trouble because the platinum broke away from the glass and created pockets of constant potential. Homemade electrodes were much more reliable and

economical.

The electrodes may be made by joining platinum wire tips to copper leads by fusing, silver soldering, or by means of mercury contact. Dirasian (1968) has had considerable experience in constructing about 200 of these electrodes. He silver soldered 3/4-inch lengths of 20-gauge platinum wire to 18-gauge copper wire. One end of soft glass tubing, about 6 mm. in diameter, was then heated to seal the platinum wire. The other end was sealed with some type of insulating material. Exposed copper wire was insulated, and a shielded cable (lead wire) was used for the connection to a potentiometer. Henry (Aug. 1960) constructed homemade electrodes in a similar fashion, except that he used mercury contact instead of silver soldering for electrical contact with the lead wire. He recommended the use of double insulated (in plastic) shielded microphone cable for this wire.

2.3.2 Standarization of Electrodes

Electrodes may be standardized (or checked) in any standard buffered solution of quinhydrone. Buffer solutions with at least 2 grams of quinhydrone per liter of solution exhibit a characteristic potential at 25°C as in the equation (Dirasian, 1968):

$$(E_c) \text{ quinhydrone} = 455 - 59.15 \text{ pH}$$

where (E_c) quinhydrone = the potential (in millivolts) of the solution with respect to the saturated calomel electrode

pH = the pH of the buffer solution.

As can be seen from the above expression, the potential decreases

approximately 59 millivolts for every unit increase in pH.

Electrodes should be checked periodically (Henry, Aug. 1960) in two buffered quinhydrone solutions (Kehoe and Jones, 1961). Most common buffers used are 0.05M potassium hydrogen phthalate (pH = 4.008 at 25°C) and a standard pH buffer of 6.86 at 25°C. Substituting into the preceding equation, it is seen that these solutions exhibit potentials of (E_c) quin. = 218 mv. and 49 mv., respectively.

Dirasian (1968) checked 72 homemade platinum electrodes in a 0.05M potassium hydrogen phthalate solution to determine the accuracy which could be expected in the calibration. A statistical analysis of the data gave a mean value of (E_c) quin. = +217.7 and 95 per cent confidence limits between 214.3 and 221.5. This indicated that reproducible, consistent readings could be obtained in a standard chemical solution.

2.3.3 Limitations of the Platinum Electrode

Various authors have expressed limitations of the platinum electrode (Henry, Aug. 1960; Kehoe and Jones, 1961; Natarajan and Iwasaki, 1970). These limitations should be recognized to enable proper evaluation of results:

1. The electrode can be influenced by all oxidants and reductants present.
2. The surface of the electrode can become coated resulting in desensitization and increased response times.
3. If exposed to strong oxidants or reductants, the electrode

may have a memory effect with subsequent residual influence.

4. The pH of the solution greatly affects the ORP. An increase of one pH unit decreases the ORP approximately 60 mv.
5. Temperature has a small effect on the ORP. With an increase in temperature of $1C^{o}$, the ORP generally decreases approximately 1 mv.
6. Response times to obtain stable readings in sewage take from 2 to 30 minutes.
7. Platinum is not inert as often thought to be. Oxygen can react with platinum to form platinum oxides on the electrode surface.
8. A film of adsorbed oxygen on the platinum can react with various other species to effect a change in ORP.

2.3.4 Cleaning of Electrodes

Frequent cleaning of electrodes is necessary to expose a clean, shiny surface and to ensure that any thin films which have accumulated on the electrode surface do not influence the measured ORP. Many methods of cleaning electrodes have been investigated. These include mechanical, chemical, electro-chemical, and ulta-sonic means. Cleaning procedures followed by some authorities are discussed in the following paragraphs.

Okey et al. (1946), in continuous monitoring of biological systems, used ultra-sonic vibrations to effect scavaging of the tip of a gold electrode. Periodic cleaning with a slurry of diatomaceous earth and water was also recommended.

Nussberger (1953) thoroughly rubbed electrodes with a slurry of Bon Ami, rinsed the electrodes and then repeated the procedure. The electrodes were stored in distilled water until use.

Henry (Aug. 1960) used a mild neutral abrasive such as Bon Ami. Diatomaceous earth was also considered satisfactory. The abrasive was used as a paste in water or dry to absorb oils and greases. The electrodes were thoroughly rinsed and then stored in distilled water for at least one day before use. Occasional cleaning with fine emery or carborundum was performed as required to remove "frosty gray areas".

Grune (1958) washed electrodes in a 1.5 to 10% HCl solution and scrubbed them with a paste of Alconox powder. Thorough rinsing with distilled water followed.

Dirasian (1968) scoured electrodes with levigated alumina. Further studies showed that any commercial or household scouring powder accomplished the same results. The electrodes were immersed in 10% HNO_3 solution for ten minutes and then thoroughly rinsed with distilled water. Electrodes were stored in distilled water at least thirty minutes before use.

Natarajan and Iwasaki (1970) found that good mechanical polishing accomplished effective cleaning with lower response times than obtained after chemical cleaning. Commercial platinum electrodes were brightened with an alumina abrasive on a metallurgical polishing wheel.

2.3.5 Precautions

Platinum electrodes demand special attention and care if reproducible, consistent results are to be obtained. Various suggestions in the literature are summarized below:

1. Electrodes must be well constructed and the platinum surface maintained in a bright, clean condition.
2. Electrodes should be checked periodically for cracks and other signs of impending malfunction.
3. Readings should be taken when the meter needle has stabilized; otherwise variable response times will produce inaccurate results.
4. A minimum of three homemade platinum electrodes should be used in biological systems (Henry, Aug. 1960; Dirasian, 1968). It is desirable to have three electrodes so that malfunctions can be detected immediately and so that the accuracy of the results can be estimated.
5. For in situ measurements the electrodes should be far enough below the surface of the sewage to ensure that readings are representative and are not affected by higher dissolved oxygen concentrations close to the surface.

2.3.6 Response Time

One disadvantage of ORP determinations in sewage is that instantaneous results cannot be obtained. The platinum electrode takes time to respond to the prevailing ORP of the biological system and to give a stable reading. Because of this, another complication

sometimes arises: if the sewage itself is not in a steady-state condition, it is not known whether electrode response or system change is being followed.

The cause of response time is not clearly discussed in the literature. Nevertheless, various factors which affect it have been isolated:

1. Electrode exposure to strong oxidants or reductants before measurement of a different solution produces a memory effect which increases the response time.
2. The nature of the solution being measured affects the response.
3. The condition of the solution (whether highly septic or oxidized) also affects response time.
4. A contaminated or poorly cleaned platinum surface increases the response time in addition to producing an incorrect reading.

2.4 In Situ Measurements of ORP

As concluded previously, O-R potentials of sewage are best determined in situ rather than from grab samples. Such a requirement demands the use of special equipment and procedure. Henry (Aug. 1968) wrote an excellent paper on the field equipment used in ORP measurements at the Miami Sewage Treatment Plant. Much of the following information is based upon his work.

Essential components of ORP field equipment are a carrying

box, platinum electrodes with suitable leads and connectors, an electrode carrier/protector, a switch box, a reference electrode (usually calomel), a suitable battery-operated pH meter (used as a potentiometer on the mv. scale), a KCl reservoir, plastic tubing plugged at one end with a glass rod, and miscellaneous solutions.

The only requirement for the carrying box is that it be big enough but not too cumbersome to carry all of the equipment. A carpenter's tool box might suffice. It should preferably be open so as to avoid time lost in opening and closing a lid and to avoid trouble with electrode leads being damaged if squeezed. Under adverse weather conditions a box with a lid is obviously better.

The electrode carrier's main function is to prevent damage to the measuring electrodes. This could be caused by clashing of the electrodes against the sides of tanks or against each other. The platinum tips could also be broken or contaminated if not held free of surrounding equipment. Electrode clips can be made by boring holes in rubber stoppers and attaching the stoppers to the carrier. The carrier can be made from non-conducting material such as asbestos cement pipe.

Three to four platinum electrodes can be used. To simplify and speed up the measuring procedure, the platinum electrode leads should go to a switch box with one connection from the switch box to the pH meter.

The calomel reference electrode cannot be used directly for in situ measurements. It is necessary to have the level of KCl inside

the electrode above the level of the solution being measured to ensure a constant flow of KCl into the solution, thereby establishing electrical contact. Otherwise, the end of the calomel electrode would quickly become plugged or contaminated resulting in unreliable readings. This problem is overcome by placing the calomel electrode in a reservoir of saturated KCl. A plastic tube full of KCl is joined by a suitable connection to the bottom of the reservoir which has a hole in it; the other end of the tube is plugged with a glass rod (not too tight or too loose). Electrical contact is established with the solution by infinitesimal leakage of KCl around the glass-plugged end of the plastic tube.

Miscellaneous solutions carried in the box may include cleaning solutions and distilled water for rinsing and storing the electrodes. Buffered quinhydrone solutions may be carried if checks on measurement accuracy are thought necessary in the field.

2.5 ORP of Sewage

Measurements of the ORP of sewage have been performed by a number of researchers investigating nearly all stages and types of sewage treatment processes. Included in the list are aeration tank profiles as well as measurements on influents, effluents, settling tanks, and anaerobic digestion tanks. Values found in the literature are shown in TABLE II; however, a word of caution is necessary regarding interpretation of these values. They are presented only to give a general idea of what values might be expected. They do not necessarily represent optimum values.

TABLE II: ORP OF SEWAGE DURING DIFFERENT STAGES OF TREATMENT

	Oxidation - Reduction Potential, E_h (mv.)				
Investigator	Primary Influent	Aeration Tank	Final Settling Tank	Secondary Effluent	Anaerobic Digester
Bargman et al. (1957)		greater than +200			
Backmeyer and Drautz (1961)	-180 to +70			+80	
Dirasian (1968)		+100 to +540	+100 to +470		-295 to -265
Grune and Lotze (1958)					-250
Hartz and Kountz (1966)					-300 to -270
Henry (Dec. 1960)	-240 to -60	+10 to +320	-220 to +320		
Hood (1948)	+280	+530			-100 to -200
Kehoe and Jones (1961)	-300 to +100				
Molof (1961)					-290 to -220
Nussberger (1953)		+320 to +500	+50 to +310		
O'Rourke et al. (1964)	+20 to +80			+130	
Rolich (1948)		+300			

As seen in TABLE II, ORP values (E_h) ranged from -300 to +100 mv. for primary influents, +10 to +540 mv. for aeration tanks, -220 to +470 mv. for final settling tanks, +80 to +130 mv. for secondary effluents, and -100 to -300 mv. for anaerobic digesters. The wide range of results listed may be due to a number of factors. Measurement error could be one possibility; however, a wide range of operating conditions encountered by different investigators would be a more plausible explanation.

The effect of dissolved oxygen on ORP has interested numerous researchers. Okey et al. (1946) stated ". . . there is every reason to believe that in an actively metabolizing aerobic system the concentration of oxygen will affect the measured potential. Most of the referenced work tends to support this, but data directly relating dissolved oxygen to (ORP) . . . are contradictory." Some values of ORP found in the literature are shown in TABLE III for sewage with no DO and saturated with DO, and values determined for distilled water are shown for comparison.

TABLE III: EFFECT OF DISSOLVED OXYGEN ON ORP

Investigator	Oxidation - Reduction Potential, E_h (mv.)			
	Sewage		Distilled Water	
	with no DO	Saturated with DO	with no DO	Saturated with DO
Henry (Dec. 1960)	+180[a]			
Natarajan and Iwasaki (1970)			+430	+520
Nussburger (1953)	-50			
Okey et al. (1946)	-100[b]	+310 to +330		
O'Rourke et al. (1964)	0			

[a] Sewage was prechlorinated.

[b] Traces of DO were found at E_h as low as -300 mv.

It is generally agreed that septic conditions in sewage are reached at an ORP between 0 and -100 mv. (E_h). However, since not all types of sewage can be considered similar, deviation from this range is possible. Okey et al. (1946) and Dirasian (1968) suggested that in aerobic processes the ORP should be maintained at or above +100 mv. (E_h) to avoid lowering the rate of oxidative destruction.

Rate of reduction curves on grab samples (decrease of ORP with time) may yield valuable information in addition to the above. The basic procedure followed consists of collecting a sewage sample in a jar and making measurements on the decrease of ORP with time. In this test the sample must be stirred and must not be allowed access to air. Results obtained by Nussberger (1953) are shown in FIGURE 2 for the mixed liquor at the ends of activated sludge aeration tanks under a wide variety of conditions. By comparison of a treatment plant's reduction rate curve with the curves shown in this figure, the extent of aeration and loading can be evaluated.

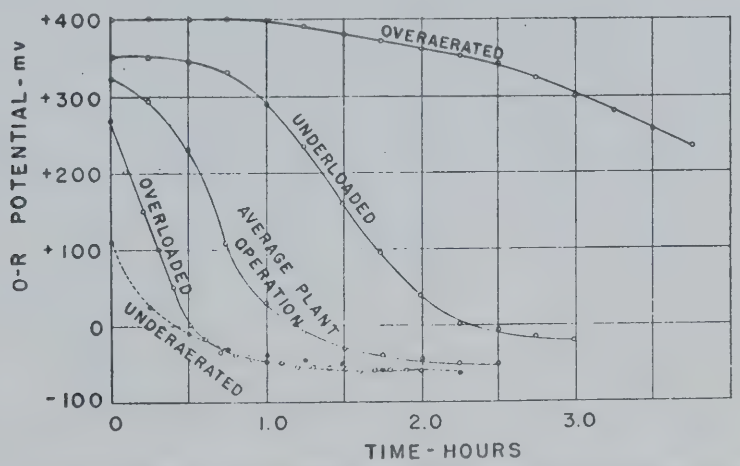


FIGURE 2: COMPARATIVE ORP REDUCTION RATE CURVES OF VARIOUS ACTIVATED SLUDGES UNDER NORMAL AND ABNORMAL CONDITIONS (NUSSBERGER, 1953)

2. 6 Summary

In a review of the literature, a wide range of information was covered. The theoretical aspects, upon which ORP measurements are based, were discussed. Considerable description of platinum electrodes was included because of the importance of using good measuring electrodes and realizing their limitations. A method for in situ measurement of ORP of sewage was explained and various values, found in the literature, were presented.

CHAPTER III

THE EDMONTON SEWAGE TREATMENT PLANT

3.1 Introduction

A description of the Edmonton Sewage Treatment Plant is necessary in order to give proper meaning and perspective to the ORP study. Since the study concentrated almost entirely on the secondary treatment portion of the plant, particular emphasis is placed on that portion in this chapter. An explanation of the secondary treatment principles involved, as well as a comparison of plant operations with those in similar plants, are also presented to give the study more depth.

3.2 Description of the Edmonton Sewage Treatment Plant

3.2.1 General

The Edmonton Sewage Treatment Plant is located on the south side of the North Saskatchewan River at 50 St. and 109 Ave. in Edmonton. Since the plant was constructed in 1956, it has gradually expanded to the size shown in FIGURE 3. An additional sludge digester, not shown on the plan, will be in operation before the end of 1973.

3.2.2 Waste Loadings

The plant handles domestic and industrial wastes from about 90 per cent of the city. Storm flows and run-off enter the sanitary

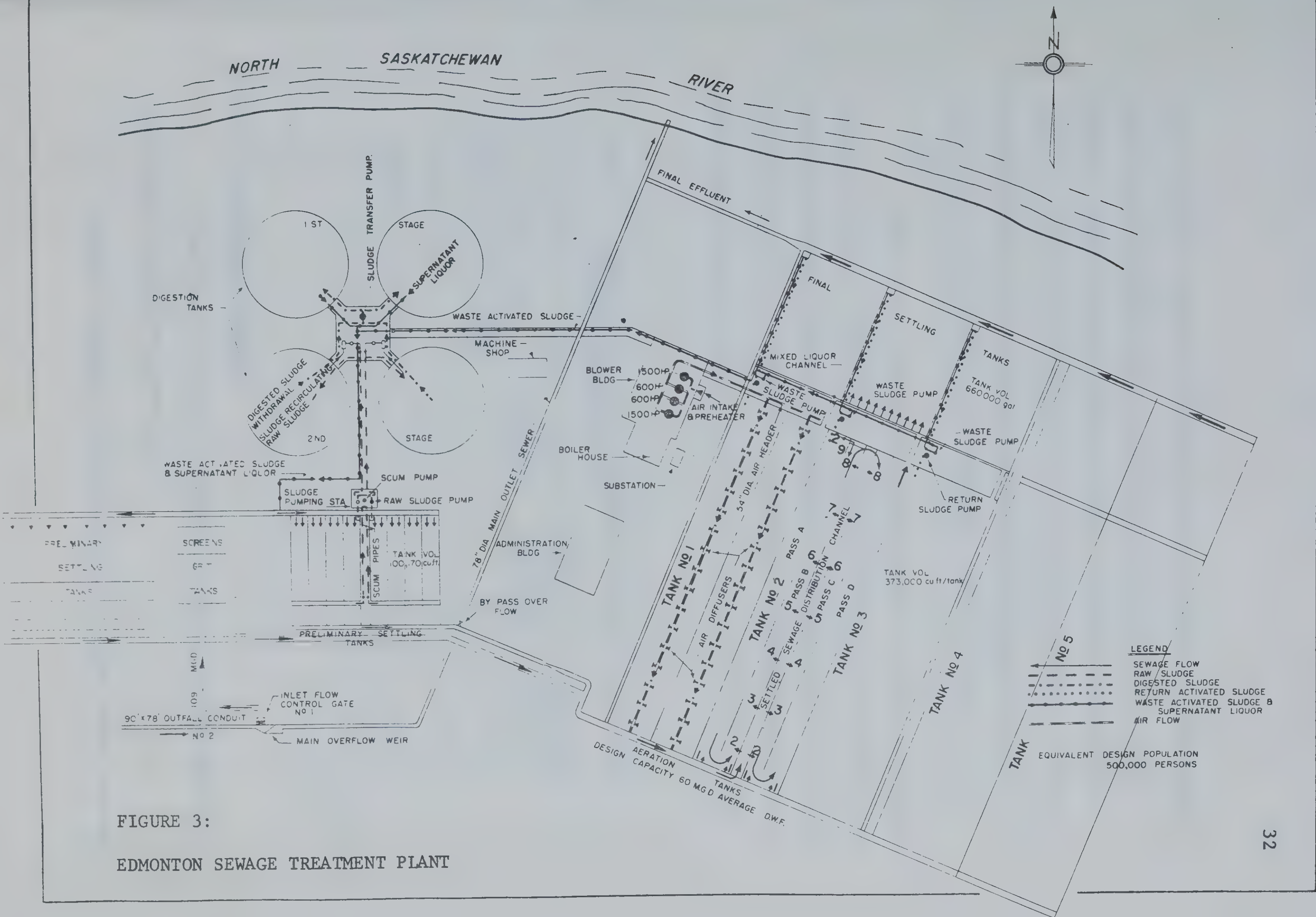


FIGURE 3:

EDMONTON SEWAGE TREATMENT PLANT

sewer system in a few areas which are not serviced with storm sewers, and ground water infiltration may be significant during run-off periods. Wastes from meat packing plants, located in the northeast section of the city, are not normally treated at the plant. Instead, the high organic loads characteristic of packing plant wastes are piped to the Cloverbar Industrial Lagoons east of the city.

Some normal loads handled by the plant are shown in TABLE IV; however, these may vary widely. Primary influent flow rates may vary from 25 to 60 MIGD daily with instantaneous rates from 15 to 105 MIGD. Organic loads may vary from 150 to 450 mg./1. suspended solids (40 to 99 per cent volatiles) and from 150 to 350 mg./1. BOD (5 day - 20^{o}C).

TABLE IV: NORMAL LOADS AND PERFORMANCE DATA FOR THE EDMONTON SEWAGE TREATMENT PLANT

Type of Load	Raw Influent	Primary Effluent	Secondary Effluent
Hydraulic load, MIGD	40	40	40
BOD, mg./1.	220	150	30
Suspended solids, mg./1.	270	160	40

3.2.3 Treatment Processes

Primary and secondary treatment processes are employed at the Edmonton Sewage Treatment Plant.

Primary treatment facilities consist of grit tanks, screens,

and primary settling tanks. The grit tanks remove coarse, heavy materials. Screen units at the ends of the grit tanks remove rags, papers and larger wastes. After screening, settleable solids are removed in the primary settling tanks. The primary sludge, thus formed, is pumped to the anaerobic sludge digesters. The overflow from the primary, termed the primary effluent, is treated further in the secondary.

Secondary treatment is accomplished by means of the contact stabilization variation of the activated sludge process. As shown in FIGURE 3, the secondary consists of five aeration tanks with complementary final settling tanks. Each aeration tank is divided equally into four passes designated as Passes 1, 2, 3, and 4. A half-section of an aeration tank is shown in FIGURE 4. Under normal operation (as of April 1973) return sludge from the final settling tanks is aerated in Pass 1 and Pass 2, sewage from the primary is introduced along the last half of Pass 3, and the combined mixture (mixed liquor) flows through Pass 4 to the final settling tanks. The activated sludge solids rapidly settle to the bottoms of the tanks, are collected at the far ends, and are returned to Pass 1. A small portion of the sludge is wasted from the system by pumping it to the primary settling tanks where it settles. The clarified liquid in the final settling tanks flows over weirs and becomes the final effluent.

Control of the aeration process is accomplished by monitoring the dissolved oxygen levels at the end of Pass 4 of each aeration tank where dissolved oxygen levels are usually maintained between 2.0

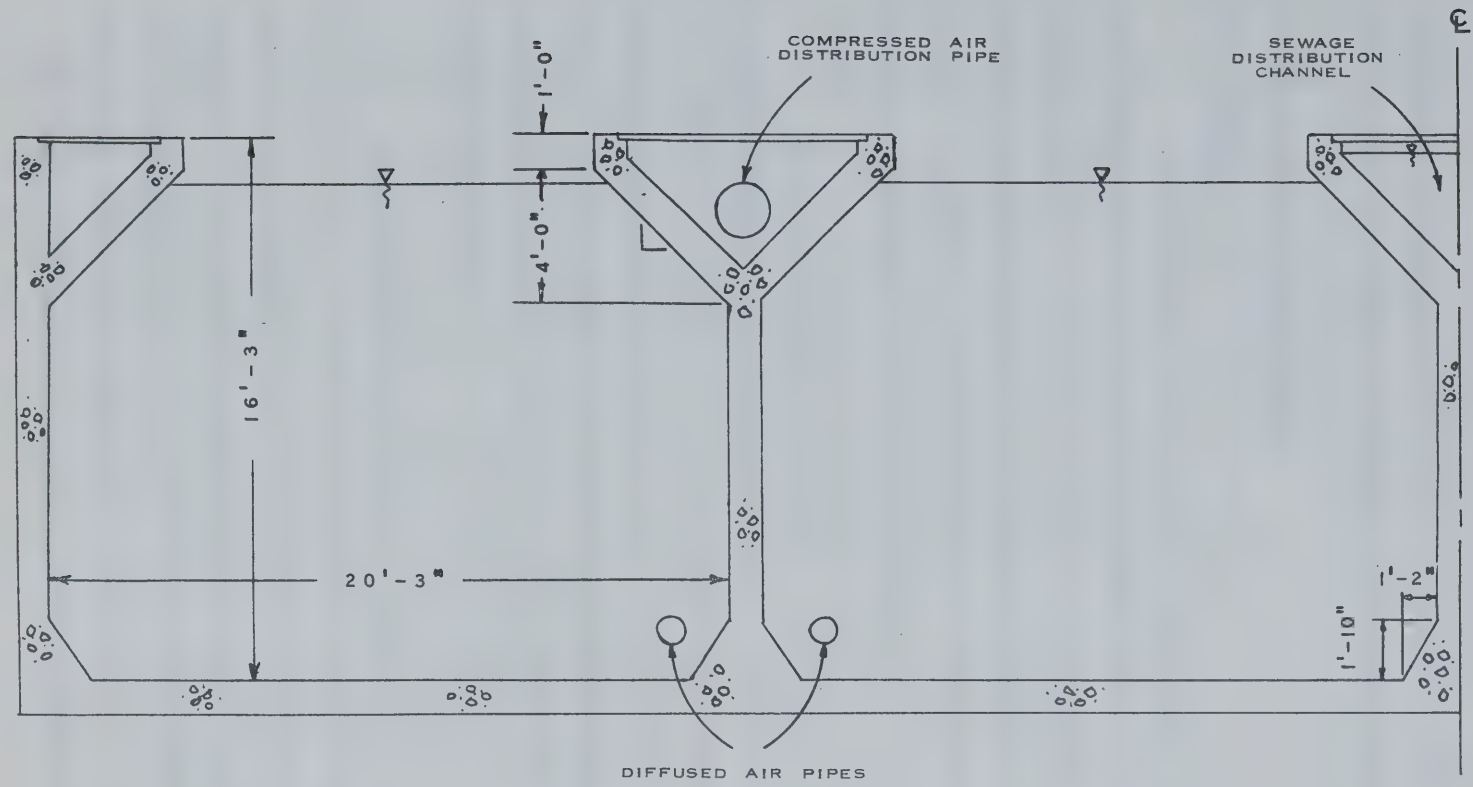


FIGURE 4: HALF SECTION OF AN AERATION TANK, EDMONTON SEWAGE TREATMENT PLANT

and 4.0 mg./1. Measurements are made with DO probes which are calibrated against the azide modification of the Winkler method.

3.3 The Activated Sludge Process

3.3.1 General

In the activated sludge process, liquid wastes are contacted with preformed biological flocs in an aerated system. The end result is the biological degradation of a portion of the organics into inorganics while the remainder is converted into additional activated sludge. The system is kept in balance by wasting a portion of the activated sludge equal to its growth increment.

Activated sludge can be defined as a flocculent assemblage of microorganisms, non-living organic matter, and inorganic materials (Rich, 1963). Included in the microorganisms are bacteria, molds, protozoa, and metazoa which are related to each other in a food chain. Complex organic compounds are decomposed by bacteria and molds which are consumed by metazoa. The latter may also feed directly upon the organic decomposers.

The term "activated" is used to describe the sludge because the surfaces of the aerated floc are highly active in adsorbing colloidal and suspended material from solution. Initially, removal of organics upon contacting with activated sludge is due mainly to the adsorption phenomenon. Oxidation of the stored organics occurs more slowly over a longer time period. When the full storage capacity of the sludge floc has been utilized, it can no longer be considered

active because its adsorptive capability is lost. Through a process called sludge stabilization, the sludge is aerated to effect oxidation of some of the stored organics and restoration of sludge activity.

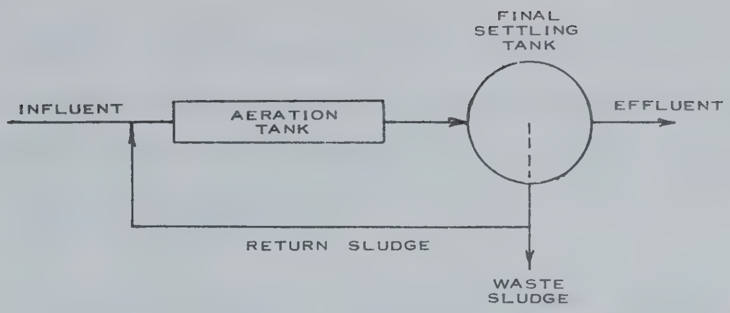
3.3.2 Conventional Activated Sludge Process

In the conventional activated sludge process, returned activated sludge is mixed with settled sewage and aerated for a period of four to eight hours in long aeration tanks. The mixed liquor from the aeration tanks flows to settling tanks where the sludge quickly settles to the bottom and the supernatant flows over weirs as the secondary effluent. Most of the settled sludge is returned to the beginning of the aeration tanks and a small portion of the sludge is wasted from the system. A schematic plan of the process is shown in FIGURE 5 (A).

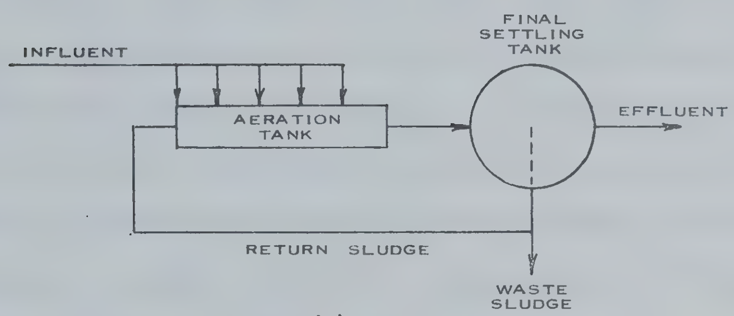
3.3.3 Modifications of the Conventional Activated Sludge Process

Various changes can be made in the conventional process to improve on its performance or to make it more economical. These modifications include the step aeration process, the contact stabilization process, the modified aeration process, and the extended aeration process (Rich, 1963; Fair et al., 1968).

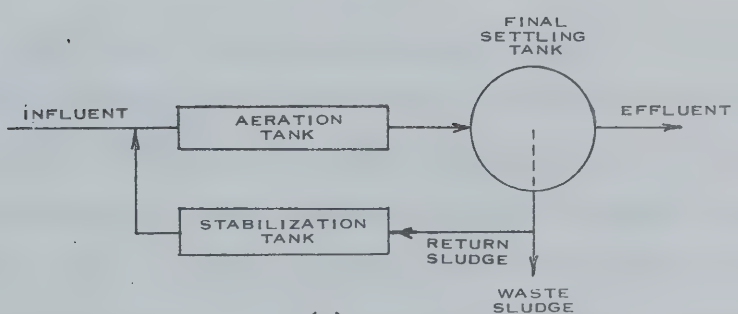
The step aeration process differs from the conventional process in that settled sewage flows into the aeration tank at different points over most of its length instead of being concentrated at the beginning. Shorter detention times and lower activated sludge concentrations in the mixed liquor are possible. The effect of shock



(A)



(B)



(C)

FIGURE 5: SOME SCHEMATIC DIAGRAMS OF THE ACTIVATED SLUDGE PROCESS (A) CONVENTION PROCESS (B) STEP AERATION (C) CONTACT STABILIZATION

loads is minimized, nutrients support the floc population more uniformly, oxygen demands drop within a narrower range, and steady-state operating conditions are approached. A schematic plan of the process is shown in FIGURE 5(B).

The contact stabilization process differs from the conventional process in that return sludge is stabilized before contacting with the organics of the liquid waste. The return sludge is vigorously aerated in a stabilization tank to restore its activity and, after mixing with the influent, it is aerated in a contact tank for a much shorter time period. The advantage of this process is that it permits a reduction in aeration tank capacity because aeration in the stabilization stage is confined to the return sludge volume. A diagram of the process is shown in FIGURE 5 (C).

The modified aeration or high rate process is used only where organic removals of a lower degree, than those for the preceding processes, are acceptable. The return sludge volume and the aeration times are less than for the conventional process. Organic removals from 50 to 75 per cent have been reported for the modified aeration process as compared to 85 to 95 per cent for the other processes.

The extended aeration process differs from the conventional process in that aeration times are significantly increased. By aerating the sludge beyond the period required to reach a wanted degree of effluent purity, the volume of sludge wasted from the system is decreased and consequently the volume of sludge handled by the

anaerobic digesters is also reduced.

Terminology, particularly with regard to the contact stabilization process, is not consistent in the literature. Goodman (1971) distinguishes the process from one he terms "two-stage aeration" strictly on the basis of aeration times. Eckenfelder (1961) does not make such a distinction and just used the term "contact stabilization". Haseltine (1961) uses a completely different name for the process, "extended reaeration". Hereafter all processes in which return sludge is stabilized before contacting with sewage are only referred to as contact stabilization unless clearly indicated otherwise. Since that is basically the process used at Edmonton, TABLE V has been prepared showing the various operating characteristics for the system as found at other plants and at Edmonton.

3.4 Operation of the Edmonton Sewage Treatment Plant

3.4.1 Primary Treatment

Little in the way of primary operational control is performed other than limiting the maximum hydraulic loading. When raw sewage flow exceeds about 90 MIGD, the excess is bypassed directly to the river.

3.4.2 Secondary Treatment

At the Edmonton Sewage Treatment Plant, the secondary influent is normally limited to 50 MIGD (as of April 1973) since primary effluent flow rates greater than this are bypassed to the river. The basic secondary treatment process used is contact stabilization. However,

TABLE V: OPERATING AND PERFORMANCE DATA FOR THE CONTACT STABILIZATION PROCESS[a,b]

Item	Goodman (1971) Contact Stabilization	Goodman (1971) Two Stage Aeration	Eckenfelder (1961) Contact Stabilization	Haseltine (1961) Extended Reaeration	Edmonton Normal Operation[c]
Aeration Tank					
MLSS (mg./l.)	3,000	3,000	2,500 - 3,300	1,700 - 5,100	1,250
RSSS (mg./l.)	6,000	6,000	4,500 - 8,600	4,200 - 10,000	4,500
Return Sludge (% of sewage flow)	100	100	44 - 100	41 - 104	25
Aeration time for mixed liquor (hr.)	0.25 - 0.50	1.5	0.24 - 1.30	0.4 - 2.2	1.75
Return sludge (hr.)	2 - 4	7.5	1.0 - 4.25	1.6 - 5.7	19
Aeration: ($ft.^3$/Imp. gal.)				1.2 - 2.0	1.5
($ft.^3$/lb. BOD removed)				675 - 1,430	1,250
Final Settling Tank					
Surface loading (ICD/$ft.^2$)				400 - 500	730
Detention time (hr.)				1.3 - 4.0	2.7
Overflow rate (ICD/ft.)				6,000 - 14,000	12,000
Sludge volume index for MLSS from aeration tanks				70 - 140	40 - 125
Overall efficiency					
% BOD removed	90 or greater	90 - 92	88 - 92	84 - 96	80
% SS removed				82 - 95	75

[a] The terms used to refer to the "contact stabilization process" by different researchers, are shown below the reseachers' names.

[b] Symbols used are explained in the List of Symbols.

[c] Values are based on a secondary influent flow rate of 8 MIGD and a return sludge rate of 2 MIGD for each of the five aeration tanks.

other modifications of the conventional process are evident to a lesser degree.

In normal operation of the Edmonton plant, sewage is distributed over the last half of Pass 3 of each aeration tank (through 7 to 9 gates); therefore the process is partly related to the step aeration process. Also since the aeration period of the return sludge is much longer than required for good BOD removal, some relation to the extended aeration process is seen. A discussion of the striking operating differences at Edmonton and at other contact stabilization plants is found in CHAPTER V.

3.5 Summary

The information presented on the Edmonton Sewage Treatment Plant indicates that wide variations in loadings are experienced. Most of the information is focussed on the secondary treatment process employed at Edmonton (contact stabilization modification of the activated sludge process) as well as the principles upon which it is based. The process was explained so that a fuller appreciation of the ORP study could be realized by placing it in the proper perspective.

CHAPTER IV

DESCRIPTION OF STUDY

4.1 Objective of Study

The main objective of the study was to determine if oxidation - reduction potential measurements in secondary aeration tanks could provide a good indication of satisfactory operation thereof. In an attempt to accomplish this objective, a variety of secondary tank operating conditions were investigated. Dissolved oxygen, suspended solids, and biochemical oxygen demand data (as determined by sewage plant personnel) were used to aid in evaluating the ORP results.

4.2 Apparatus

4.2.1 ORP Field Equipment

Henry (Aug. 1960) has emphasized the importance of measuring O-R potentials in situ rather than on grab samples. An ORP field kit similar to Henry's, therefore, was designed.

The equipment was comprised of four homemade platinum electrodes with an electrode protector/carrier, a calomel reference electrode, a saturated KCl reservoir with a connecting plastic tube, a four-way switch box, a pH meter with a millivolt scale, and a carrying box as shown in FIGURE 6.

The homemade platinum electrodes were constructed with 20

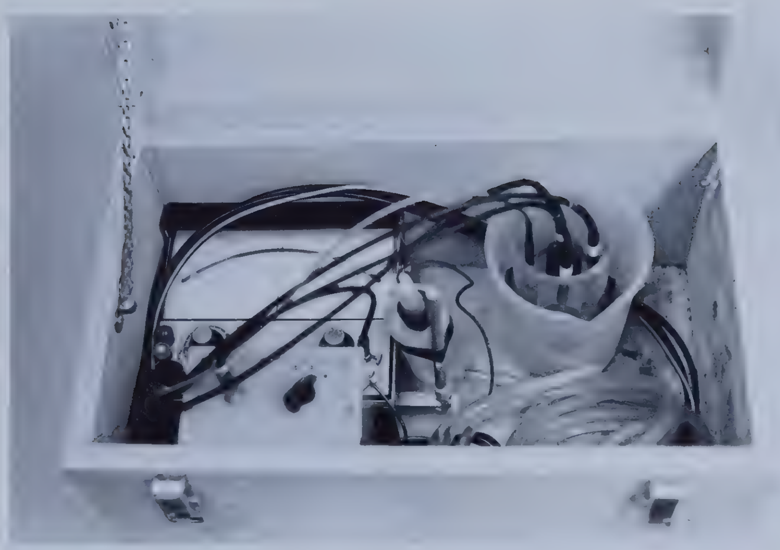


FIGURE 6: PICTURE OF ORP FIELD KIT - CARRYING BOX, SWITCH BOX, METER, SATURATED KCl RESERVOIR AND CALOMEL ELECTRODE, KCl TUBE, PLATINUM ELECTRODE PROTECTOR/CARRIER, PLATINUM ELECTRODES AND VARIOUS WIRE CONNECTIONS

gauge platinum wire, double plastic insulated copper wire, and a 5½-inch long x 7 mm. diameter soft glass tubing. A 1¼-inch length of platinum wire was silver soldered to the copper wire and sealed in the glass tubing by heating with natural gas over a Bunsen burner. Approximately 3/4-inch of platinum was allowed to protrude beyond the sealed junction. The other end of the tube was insulated with silicone sealant and heat-shrink tape. FIGURE 7 shows the components of the platinum electrode.

An electrode protector/carrier was designed for the obvious functions as described by its name. An eight-inch long x three-inch diameter piece of lucite tubing was used for this purpose. Four holes were drilled through the tubing at equal distances around the circumference. Four rubber stoppers were drilled diametrically with a hole 1/4-inch from the smaller end which was also slit through to the drilled hole. The larger end was cut 1/8-inch wide x 1/8-inch deep along the diameter at a 90 degree angle to the drilled hole. The smaller ends of the rubber stoppers were pushed snuggly into the lucite holes and were secured with a rubber "O" ring around the outside of the tubing and the stoppers' grooves. The stoppers then functioned as electrode clips and the tubing as a protector. The arrangement is shown in FIGURE 8.

A calomel electrode was used as the reference electrode. It could not be used directly for in situ measurements and had to be placed in a reservoir of saturated KCl. The reservoir was fashioned from a small plastic bottle, the bottom of which was drilled to a suitable diameter to hold a rubber stopper; the rubber stopper was

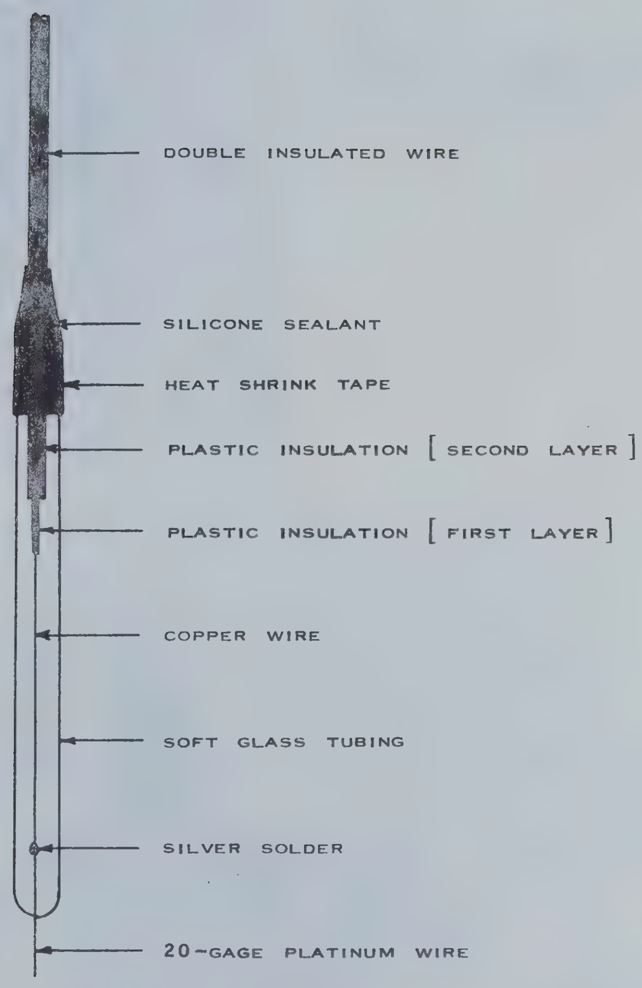


FIGURE 7: HOMEMADE PLATINUM ELECTRODE

FIGURE 8:

PICTURE OF ELECTRODE PROTECTOR/CARRIER AND PLATINUM ELECTRODES

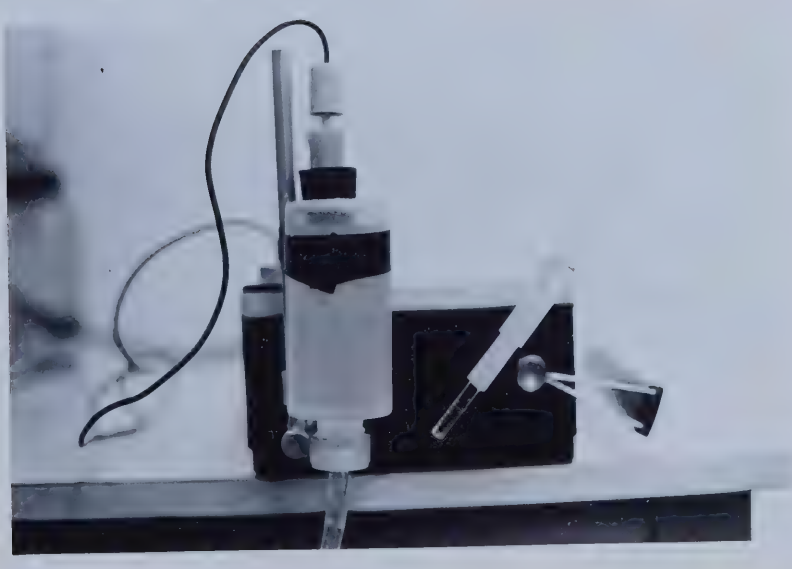


FIGURE 9: PICTURE OF SATURATED KCl RESERVOIR WITH CALOMEL ELECTRODE, KCl TUBE CONNECTION, AND GLASS PLUGGED END OF KCl TUBE (METER IN BACKGROUND)

drilled to a suitable diameter to hold the reference electrode. A small hole was punched through the screw cap of the plastic bottle and a piece of 3/8-inch diameter plastic tubing was connected to the cap. The other end of the tubing was plugged moderately tight with a glass rod. The bottle was inverted and the apparatus assembled as shown in FIGURE 9.

A four-way switch box was constructed so that ORP readings with each platinum electrode could be taken without constantly inserting and removing the electrode jacks in the meter.

A battery operated Orion specific ion meter, Model 401, was used for the ORP measurements. Specifications, as listed in the manual for the meter, gave a scale range of $\pm$ 700 mv., repeatability of $\pm$ 1.5 mv., and absolute accuracy of $\pm$ 4 mv. One lead from the switch box and one lead from the calomel cell were connected to the meter.

Calibration of the apparatus was performed using quinhydrone in two different buffer solutions: 0.05 M potassium hydrogen phthalate solution (pH = 4.00 at 25°C) and a pH 6.86 buffer (at 25°C). Quinhydrone in excess of 2 grams per liter was added to each solution. The readings obtained were compared with the theoretical values of E_c = 218 mv. and 49 mv. for pH 4.00 and pH 6.86 buffers respectively.

4.2.2 <u>ORP Reduction Rate Apparatus</u>

An apparatus was assembled to measure the rate of change of ORP of sewage grab samples without access to an external air supply. A 32-oz., wide-mouthed jar with a rubber stopper was used in such

determinations.

Six holes were drilled through the rubber stopper so that four platinum electrodes, a calomel electrode, and a thermometer could easily fit through. A tight fit was not desired because of possible breakage problems. To ensure a good seal around the probes a thin rubber membrane, with holes smaller than but aligned with those of the stopper, was glued to the bottom of the stopper. No overflow was required for the apparatus because sufficient volume of sample could be displaced simply by inserting the rubber stopper in the jar after filling it with a sample.

Constant stirring of the sample during testing was achieved by placing a small magnet in the bottom of the jar and using a magnetic stirrer. A picture of the apparatus is shown in FIGURE 10.

4.2.3 DO Equipment

Dissolved oxygen determinations were made by sewage plant personnel using a dissolved oxygen analyzer (Model 1131-MS as manufactured by Ionics Incorporated, Watertown, Massachusetts). After calibration of the instrument against the Winkler method for dissolved oxygen, the DO could be determined within $\pm$ 0.3 mg./l. after 1/4 to one minute response times, according to the instrument manual. The oxygen probe consisted of a thallium measuring electrode in conjunction with a reference electrode. With the application of an external voltage, the thallium corroded at a rate dependent upon the dissolved oxygen concentration.

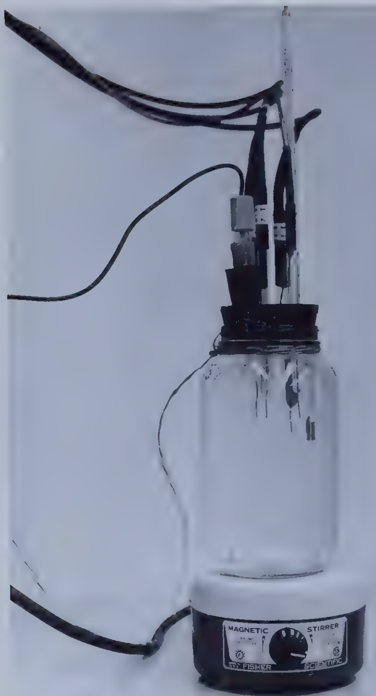


FIGURE 10:

PICTURE OF ORP REDUCTION RATE APPARATUS

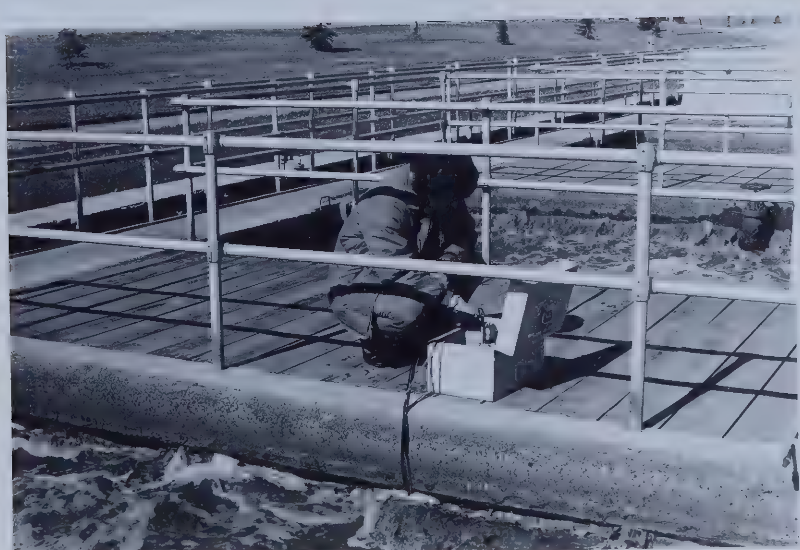


FIGURE 11: PICTURE OF AUTHOR TAKING IN SITU ORP MEASUREMENT IN AN AERATION TANK, EDMONTON SEWAGE TREATMENT PLANT

4.3 Measurement Procedure

ORP profile and reduction rate measurements were taken by the author mainly on the secondary aeration tanks. Supplementary data was obtained from dissolved oxygen profiles performed by plant personnel. Plant data on biochemical oxygen demands, suspended solids, and flow and aeration rates were obtained from monthly summary sheets.

4.3.1 ORP Profiles

Five different secondary operations were investigated for the purpose of evaluating the significance of ORP measurements under a wide range of conditions. In order to distinguish any one of the five operations from any of the others, only a short description, characteristic of the main operational change, was made in each case. However, a change in one operational parameter often necessitated a change in others if reasonable treatment efficiencies were to be obtained. The various operations are explained fully below:

1. Normal Operation - This was the normal method of secondary operation used at the Edmonton Plant. Return sludge was aerated for 19 hours before introduction of sewage through nine gates over the last half of Pass 3. A wide range of conditions, particularly with respect to suspended solids levels, existed under normal operation as described in TABLES E1 and E3. Other operations are compared with the normal in TABLE VI.
2. Step Aeration - Sewage was introduced at points along Passes 2 and 3 rather than just over the last half of Pass 3.

TABLE VI: RATIO OF OPERATING VARIABLES FOR AERATION TANK 3 (TEST TANK) TO THE AVERAGE FOR AERATION TANKS 1, 2, 4, AND 5 (CONTROL TANKS), EDMONTON SEWAGE TREATMENT PLANT, MARCH AND APRIL 1973[a]

Operating Condition	Secondary Influent Q	Return Sludge Q	Return Sludge SS	Mixed Liquor SS	Aeration Q	Points of sewage addition in Tank 3
Step aeration	1.00	1.00	1.15	1.05	1.00	over Passes 2 and 3
Increased hydraulic load	1.55	1.40	1.20	1.10	1.40	over Passes 2 and 3
Normal	1.00	1.00	1.00	0.95	1.00	over last half of Pass 3 (same as Tanks 1, 2, 4, and 5)
Reduced aeration	1.00	1.00	1.00	0.90	0.75	over last half of Pass 3 (same as Tanks 1, 2, 4, and 5)
Increased suspended solids	1.00	1.75	2.20	2.55	1.50	over last half of Pass 3 (same as Tanks 1, 2, 4, and 5)

[a] Absolute values of variables are shown in TABLES E2 and E3.

3. Increased Hydraulic Load - Sewage was introduced through an additional five gates (9 + 5 = 14 gates total) along Passes 2 and 3. Aeration and return sludge rates were increased to compensate for the higher hydraulic load.
4. Decreased Aeration - Operation was normal except that aeration rates were reduced about 25%.
5. Increased Suspended Solids - Suspended solids concentrations in the return sludge and the mixed liquor were increased substantially above the normally low levels. The return sludge rate was also increased to help maintain higher MLSS. Aeration rates were increased to allow for the higher oxygen demand of the solids.

Throughout the study, operational changes were only performed on Aeration Tank 3, the test tank; while Aeration Tanks 1, 2, 4 and 5, the control tanks, remained unaltered. The operational data for Tank 3, under the various operations examined, is presented in TABLE E2. Similar data for the other tanks is presented in TABLE E3.

TABLE VI summarizes the various operating conditions in Tank 3 by comparing it to the operations of the other tanks.

Before electrodes were used in profile measurements on a given day, they were carefully cleaned with Sparkleen. The soap was applied dry to filter paper and the platinum electrode tips were rubbed briskly. A slurry of Sparkleen and distilled water was occasionally used. The electrodes were then thoroughly rinsed with distilled water and stored in fresh distilled water at least ten minutes before use.

Approximately once every two weeks the electrodes were soaked in a 0.1N nitric acid solution after cleaning with Sparkleen. When electrodes were not in use, they were stored in distilled water. Occasionally the electrodes were checked in standard buffered solutions with quinhydrone to ensure that the initial calibration was still valid.

The procedure followed in making ORP profile measurements was as follows:

1. The elctrode protector/carrier and the glass-plugged end of the KCl-filled tube were placed about one foot below the free surface of the sewage.
2. The meter was turned on and an initial "time = 0" reading was taken 30 seconds after Step 1, above. Readings were taken with each electrode by switching consecutively to each of the four switch positions for the platinum electrodes.
3. Other sets of four readings were taken 2, 5, 10 and 15 minutes later if necessary; that is, until a stable reading was obtained. Readings were considered stable if none of the four readings differed from the corresponding previous reading by more than 10 mv. or if this difference was less than 5 mv. for three of the four electrodes.
4. Between profile measurements, electrodes were stored in buffered quinhydrone solutions having potentials approximating those of the sewage to be measured. This was found necessary, as explained in Section 5.2.2, in order to reduce long electrode response times a reasonable degree.

5. If stable readings for three of the four electrodes did not agree within 40 mv., all of the electrodes were checked and recleaned. Faulty electrodes were replaced.

Measurement locations along the aeration tanks were chosen such that a well defined profile curve could be drawn. The beginning, midpoint, and end of each pass were the widest spacings of locations investigated. Where measurements were found to change rapidly within a short reach of a pass, measurements were also taken at the quarter points. To ensure that the electrodes were fully immersed during measurement, readings were taken only on the side of the pass towards which the sewage flow headed as shown in FIGURE 11. This flow pattern was induced by diffused air rising on the opposite side of the pass, causing a considerable circulatory movement of the liquid as compared to its longitudinal movement.

In addition to the measurements within the aeration tanks, readings were taken on the secondary influent and effluent. The influent location was at the beginning of the sewage distribution channel (between Pass 2 and Pass 3) for the aeration tank being studied. The effluent location was at the upper end of the final effluent weir which was closest to the corresponding aeration tank.

4.3.2 ORP Reduction Rates

Various ORP reduction rate measurements were made on samples in a stoppered jar. Measurements were taken with four clean platinum electrodes in conjunction with a calomel reference electrode which was

immersed directly rather than using the KCl-filled tube. Other measurements taken were initial and final pH readings and continuous temperature readings (on some samples).

The main purpose for taking the reduction rate readings was to compare the Edmonton Plant's operation to that for other plants and thereby determine the status of the system: overaerated, underloaded, average, overloaded, or underaerated. Measurements, for this purpose, were taken on the mixed liquor at the end of Pass 4 of each tank under normal operation as well as Tank 3 under various different operations.

Another reason for taking these measurements was to determine the ORP stability of the system at various locations. Samples of return sludge and mixed liquor were taken at different locations in Tank 1 and measurements compared. Samples of secondary influent and effluent were also taken for the same purpose.

4.3.3 DO Profiles

Sewage plant staff measured dissolved oxygen levels along the aeration tanks under normal and other operating conditions as described in Section 4.3.1. The DO probe was checked each day before use against another probe which had been standardized against the azide modification of the Winkler method for dissolved oxygen determinations. DO profile measurements required two people: one for taking readings and one for moving the probe to each location.

4.3.4 Miscellaneous

Various 24-hour composite samples were collected by sewage

plant personnel as part of a regular sampling program. Laboratory staff at the plant performed the analyses on the samples.

Results of interest to this study included data on secondary influent, return sludge, mixed liquor, and final effluent for each tank. BOD (5 day - 20°C) tests were run on secondary influent and effluent samples. Suspended solids were determined on all of the above samples.

Additional information, as supplied by the plant, included flow rate and aeration rate data.

4.4 Summary

Numerous measurements in addition to O-R potentials were taken on the secondary aeration tanks, under various conditions, to determine the significance of ORP measurements. Only ORP measurements, in situ and in jars, were taken by the author with special equipment designed for that purpose. All other measurements were performed by the plant staff and the results obtained by them were used herein.

CHAPTER V

RESULTS

5.1 Introduction

In this chapter, the results of the investigation are presented and analyzed. The results considered include the problems encountered, various ORP profiles, a few DO profiles, ORP reduction rates, and plant performance data. Emphasis is placed especially upon ORP profiles and their relation to DO profiles and plant performance.

5.2 Problems Encountered

5.2.1 Electrode Construction

An initial problem with electrode construction in January and February of 1973 delayed the start of the ORP study until March. The problem manifested itself in poor agreement between platinum electrode readings despite thorough cleaning of the probes. The source of the problem was traced to improper electrode construction with hard glass tubing instead of soft glass tubing which was recommended in the literature. The hard glass-platinum seal proved to be unsatisfactory even when fiberglas was molded around the junction. Finally, heating soft glass tubing with natural gas (methane) was found to result in a satisfactory seal and, consequently, reliable electrodes.

A minor problem with electrode construction originated from

poor electrical connections. During a two-month period, two of six electrodes used apparently failed for this reason. The poor connections may have been located at the soldered junction of the platinum and lead wires and/or at the soldered junction of the lead wires and electrode jacks. In both cases the faulty electrodes were replaced immediately after the first signs of malfunction.

5.2.2 Electrode Response Time

The times required for electrode readings to stabilize varied considerably. The response times for electrodes in buffered quinhydrone solutions ranged from zero to five minutes. In sewage, they ranged from zero to 30 minutes, although some doubt existed regarding the latter value because changes may have been due to a change in ORP rather than a time response delay.

Average response times in ORP profile determinations were about five minutes. However, on some days a ten-minute wait was required for most of the readings to reach equilibrium. This serious disadvantage of the measurement was remedied to some extent by storing the electrodes, between readings, in buffered quinhydrone solutions having potentials approximating those to be measured. By following this procedure and making intelligent guesses of ORP, response times were reduced to less than two minutes in most instances.

The effect of treating electrodes in the above manner was checked to determine if the final readings were influenced in any way. FIGURE 12 shows the average response time curves for platinum electrodes stored first in distilled water before measurement, and then in a

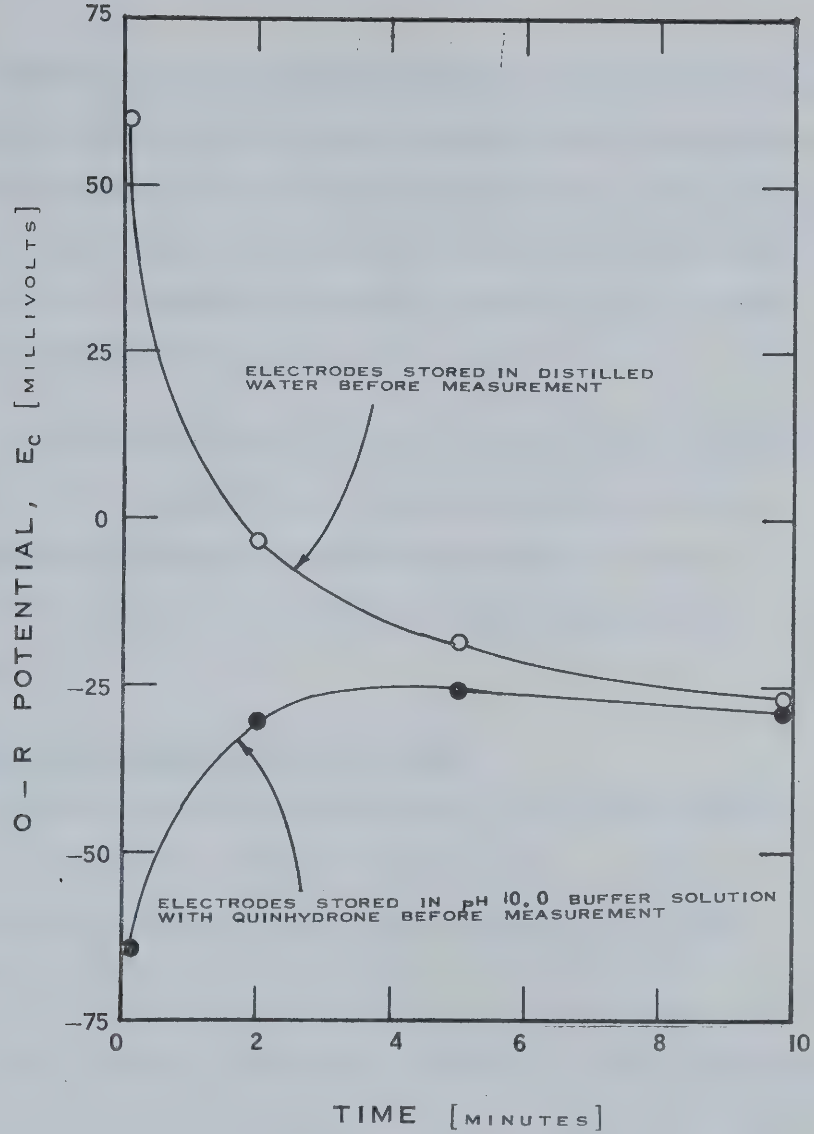


FIGURE 12: AVERAGE ELECTRODE RESPONSE CURVES FOR IN SITU ORP MEASUREMENTS AT THE BEGINNING OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT, MARCH 23, 1973

buffered quinhydrone solution before measurement. Three determinations with the former solution and four with the latter were made and averaged to minimize the effect of an unstable system ORP. As can be seen in the figure, the stable values agreed closely in each case and therefore storage of probes in buffered quinhydrone solutions did not significantly alter the ORP results.

In several measurements, response times for each electrode were not the same. One particular electrode sometimes was found to react significantly slower to the ORP being measured. However, response times for the other electrodes did not appear to vary appreciably.

5.2.3 Variations between Electrode Readings

Improper electrode construction has already been mentioned as one cause of disagreement between electrode readings. Significant variations with properly constructed electrodes were also found periodically.

On two occasions readings were taken with a newly constructed electrode, stored in distilled water for 24 hours before use, along with three older electrodes. Stable readings were found to be from 20 mv. to 40 mv. higher for the new electrodes than the average for the old electrodes. During subsequent profile measurements, however, the readings among all of the probes agreed closely.

Good agreement among electrode readings in standard quinhydrone solutions in no way indicated that similar behavior might

exist in sewage. This disparity apparently resulted from poorly cleaned electrodes which were not affected nearly so much in quinhydrone as in sewage. ORP measurements on distilled water, as well as sewage, appeared to be quite sensitive to the quality of cleaning. Consequently, each ORP profile and reduction rate determination was preceded by a check of the range of distilled water readings which seemed to indicate whether or not the probes had been satisfactorily cleaned.

5.2.4 Accuracy of the Data

Some reservations about the accuracy of plant data have been expressed in Section 1.2.2 and are not restated in this section. The discussion herein is concerned principally with the accuracy of ORP data as determined in standardization, profile, and reduction rate measurements.

In TABLE VII the results of electrode standardization are shown. Average readings for quinhydrone in a pH 4.00 buffer and pH 6.86 buffer were E_c = 214 mv. and 53 mv. respectively at a temperature of 21.5°C. Correcting these readings to 25°C, the values would be 211 mv. and 50 mv. (E_c) as compared to the theoretical values of 218 mv. and 49 mv. (E_c), respectively. Therefore, it appeared that the average electrode reading underestimated the true potential by one to seven millivolts.

TABLE VII: AVERAGE READINGS FOR STANDARDIZATION OF ELECTRODES

Date	Average Reading, E_c (mv.)		Temperature of solution (°C)
	Quinhydrone and pH 4.00 buffer	Quinhydrone and pH 6.86 buffer	
March 9	220	60	21.5
March 14	209	-	20.5
March 19	212	50	20.0
March 21	218	51	21.5
March 28	-	52	20.5
March 29	-	56	21.5
March 31	208	43	23.0
April 19	218	57	22, 23 (respectively)

In ORP profile measurements, generally good agreement was obtained between four electrode readings. When the range of one set of readings was greater than 40 mv., the worst reading was rejected. In TABLE D1 and TABLE D2 the standard deviations for each set of readings are shown along with the average readings. After rejection of some individual readings because of poor agreement and/or much slower response times, an average standard deviation of 6 mv. for aeration tank measurements was achieved.

Variations between electrode readings in reduction rate tests were substantially greater than in profiles, particularly over the steep portions of the curves where standard deviations of readings

often reached 50 mv. This possibly reflected a difference in response times for the electrodes.

The accuracy of DO profile data may have been affected by the procedure followed in taking the measurements. Sometimes the thallium electrode was exposed to the atmosphere for time periods in excess of ten minutes. This could have allowed a protective oxide coating to form on the electrode, thereby giving poor results. Also it should be noted that data at low DO concentrations could not be considered very accurate. For example, if the instrument reading was 0.5 mg./l., the true DO could be as low as 0.2 mg./l. or as high as 0.8 mg./l. ($\pm$0.3 mg./l.)

5.3 ORP Profiles

5.3.1 Normal Operation

ORP profile data, obtained for Aeration Tanks 1 to 5 under normal operation, is presented in TABLE D1 and depicted in FIGURE A1. The form of each curve was basically the same: the ORP rose quickly in Pass 1, levelled considerably in Pass 2, declined drastically in Pass 3 (because of sewage addition), and increased once again in Pass 4. A narrow variation in O-R potentials was found at the beginnings as well as the ends of all aeration tanks with much wider variations at interior locations, particularly over the first half of Pass 3. Despite the small differences in values for the aeration tank effluents, considerable variation was observed for the secondary (final) effluents.

Average ORP and DO profiles for the aeration tanks under

normal operation are shown in FIGURE 13, which summarizes data from TABLES D1 and D3. The average O-R potentials at the start, one-quarter, one-half, three quarter and end points of the tanks were approximately E_h = 200 mv., 280 mv., 300 mv., 180 mv., and 260 mv., respectively. An interesting observation was that the maximum ORP of the return sludge was greater than the maximum for the mixed liquor by 40 mv. (300 - 260) despite the fact that the mixed liquor contained greater concentrations of dissolved oxygen.

5.3.2 Step Aeration

Two ORP profiles of Aeration Tank 3, with sewage distributed over Passes 2 and 3, are shown in FIGURE A2. As expected, the overall variation of the O-R potentials along Pass 2 and Pass 3 was much less than that found under normal operation. The O-R potentials at the start and end of the aeration tank were approximately the same as for normal operation despite considerable variations between these locations. Also, at the end of each pass and the start of the next, the potentials sometimes varied widely.

At the end of Pass 2, the ORP rose sharply although sewage was added near this point. In searching for a reason for this phenomenon, it was observed that the end of the sewage distribution channel was aerated and this caused a circulation of the sewage between the end of the distribution channel and the closest open gate in Pass 2. The ORP of the sewage influent at this point was determined in one measurement to be 220 mv. compared to 70 mv. at the beginning of the sewage distribution channel. The rise in the profile at the end of Pass 2

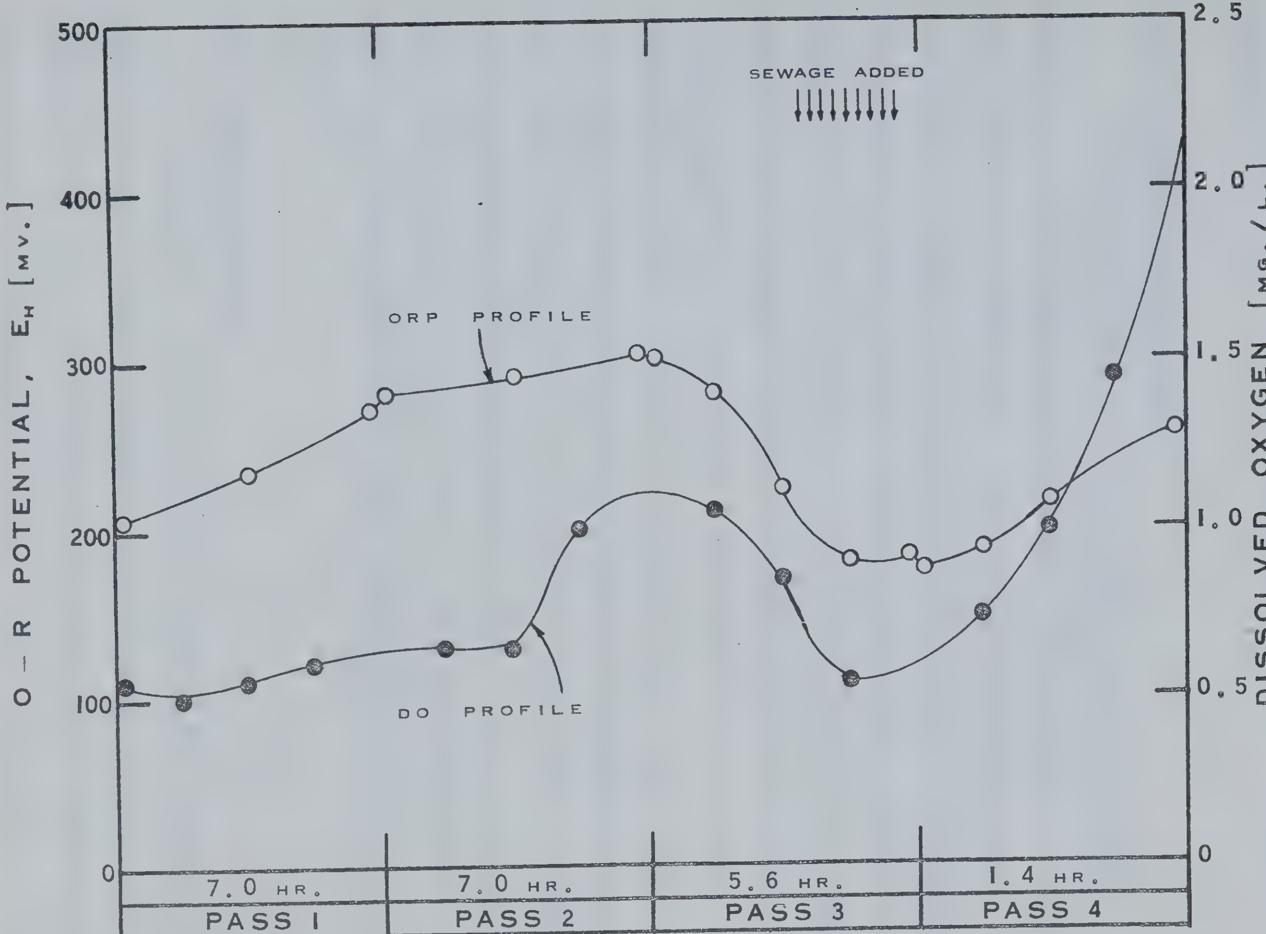


FIGURE 13: AVERAGE ORP AND DO PROFILES OF AERATION TANKS 1 TO 5, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

[a] Supplementary data is contained in TABLES D1, D3, and E1.

was therefore due to the addition of sewage with a higher ORP at that location.

5.3.3 Increased Hydraulic Load

Increasing the sewage influent flow rate, as explained in Section 4.3.1, was accomplished by opening five more gates along the sewage distribution channel for a total of (9 + 5) 14 open gates. The influent was added quite evenly over Passes 2 and 3 and represented approximately a (5/9 x 100) 55% increase in flow rate. A visual comparison of flows over the final effluent weirs of each settling tank showed a definite increase in flow for Aeration Tank 3; however, the estimated magnitude of the increase unfortunately was not certain. The ORP profiles as shown in FIGURE A3 resembled those for what was termed "step aeration" because the secondary influent was distributed over Passes 2 and 3 in each case. A considerably lower profile would have been expected with the increased hydraulic load if the aeration rate had not been increased. In fact, this was increased sufficiently to result in a slightly higher ORP profile than for the step aeration operation.

5.3.4 Reduced Aeration

ORP profiles of Aeration Tank 3, under a 25% reduction in aeration rates, are shown in FIGURE A4. Conspicuous was the overall flatness of the curves and the considerable reduction in potentials at all locations. The maximum ORP variation within the profiles was only 70 mv. and in comparison to normal profiles the potentials were 45 mv. to 190 mv. lower. The minimum ORP was about 95 mv. at the beginning

of the aeration tank and the maximum about 165 mv. at the one-half point.

5.3.5 Increased Suspended Solids

With a substantial increase in suspended solids in Aeration Tank 3, two ORP profiles were obtained as shown in FIGURE A5. Considerable variations were found in the values for the return sludge in Passes 1 and 2, possibly reflecting the effects of different aeration rates during different times of the days. The overall form of the curves were quite similar to those for normal operation and the magnitude of readings was within the same range as the normal.

5.3.6 Miscellaneous

In the initial stages of the study, two ORP profiles of Aeration Tank 3 were found which could not be easily categorized into a particular type of operating condition. They are presented only for the sake of comparison with DO profiles as shown in FIGURES B1 and B2. The aeration was not increased uniformly for the entire length of Tank 3 but only for Passes 1 and 2. Also, the sewage was distributed over the length of Passes 2 and 3. The magnitude of the flow was uncertain because three of the gates in Pass 2 were later observed to be plugged. The form of the curves was similar to that under normal operation; however, the curves were shifted noticeably upwards to about 400 mv. for the return sludge and 250 to 350 mv. for the mixed liquor.

5.4 Dissolved Oxygen and ORP Profiles

5.4.1 Normal Operation

Average DO and ORP profiles for normal operation of the aeration tanks are shown in FIGURE 13. Local maxima and minima for the two curves occurred at identical locations; however, the absolute maximum and minimum for each curve occurred at different locations. The two curves were obtained from measurements taken on different dates so that a comparison of these results, beyond that of the above, would prove of little value. It should be noted that the individual DO profiles often changed widely from hour to hour as well as from day to day.

5.4.2 Other Operations

Four other DO and ORP profiles are shown in FIGURES B1, B2, B3, and B4. The DO and corresponding ORP profile in each case were taken roughly at the same times so that reasonable comparisons could be made.

FIGURES B1 and B2 show the profiles obtained under the miscellaneous operating condition which was described in Section 5.3.6. As observed for normal operation, the local maxima and minima occurred at identical locations although such was not necessarily true for the absolute maximum and minimum for each curve. Generally, at ORP values greater than 350 mv., a small change in ORP was accompanied by a large change in DO. At ORP values less than 300 mv. a moderate change in ORP was accompanied by little change in DO. Also to be observed from the figures is the fact that considerably different values of DO occurred at a given ORP and vice versa.

IN FIGURE B3 the DO and ORP profiles, determined for operation under increased hydraulic load, are shown. The DO curve changed very little over Passes 1, 2, and 3, remaining fairly stable around 0.4 mg./l. However, a rapid rise in DO was observed in Pass 4. The addition of sewage produced no noticeable effect on the DO curve, but was readily apparent on the ORP curve.

With the suspended solids concentrations increased in Aeration Tank 3, DO and ORP profiles were found as shown in FIGURE B4. Again, the DO curve over most of the tank was very flat, rising only slightly at the end of Pass 1, and significantly not until the end of Pass 4. The ORP curve reflected the effects of sewage addition with a sizable drop in Pass 3, whereas the DO curve gave no such indication.

5.4.3 DO - ORP Relationship

If the DO and ORP results from Section 5.4.2 are plotted against each other, curves are obtained as shown in FIGURE 14. The data has been separated into that for the return sludge and that for the mixed liquor with data for transitional locations in Passes 2 and 3 being ignored. A considerable spread of results was noted in each case indicating that ORP depended upon other factors besides DO. Also, the mixed liquor ORP values were approximately 100 mv. lower than the return sludge values at corresponding DO values. This emphasized even more strongly that a direct relationship between the two variables did not exist.

5.5 ORP Reduction Rates

It should be noted that in reading ORP reduction rate curves,

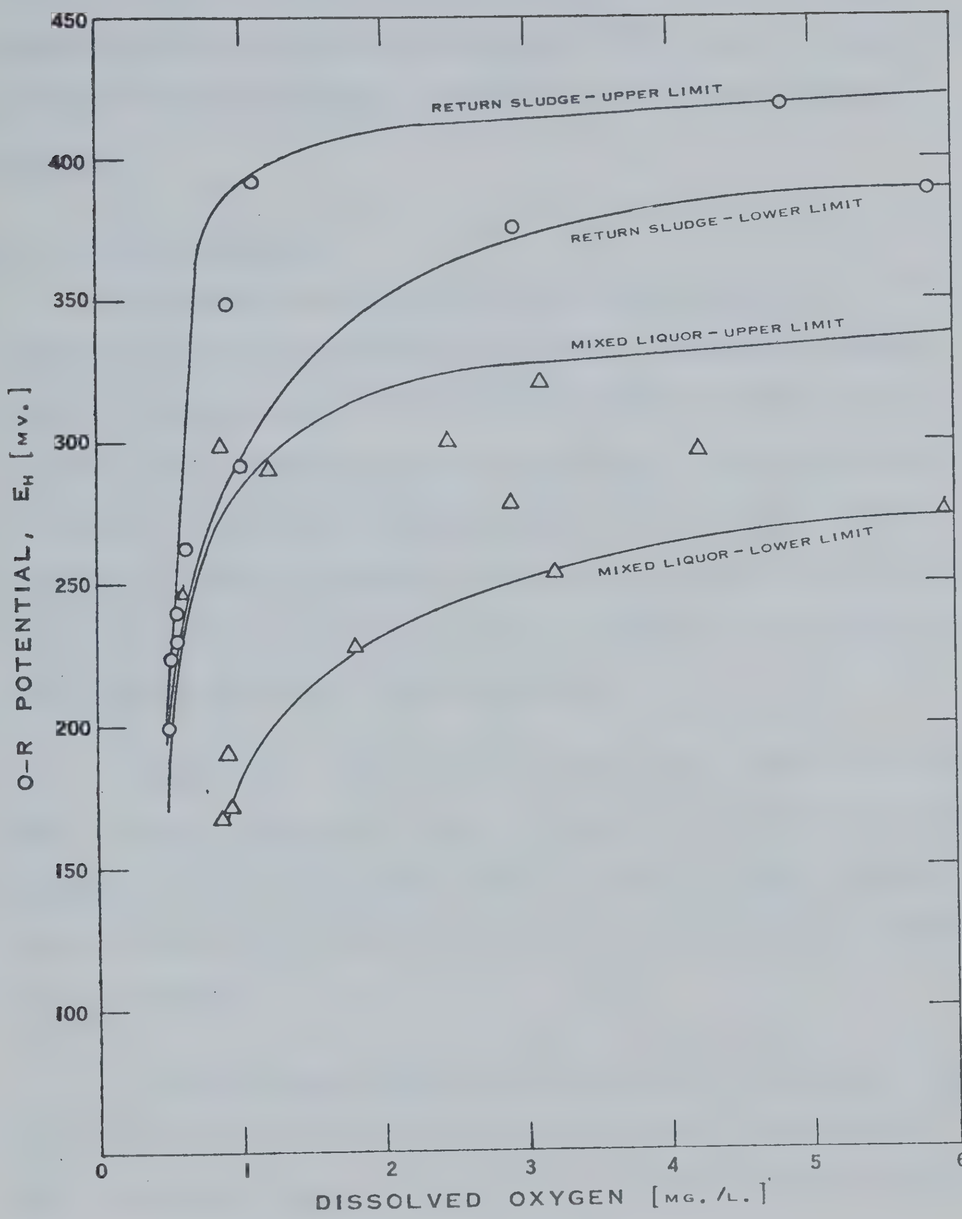


FIGURE 14: VARIATION OF ORP WITH DO IN AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT [a]

[a] Data obtained on March 12, 14, 27, and April 19, 1973 (See Table D4)

the initial values of ORP should not be considered very accurate because of slow electrode response times. Also, variations between individual electrode readings were substantially greater than for profiles.

5.5.1 Various Locations

ORP reduction rate curves for the return sludge and mixed liquor at various locations in Aeration Tank 3 are shown in FIGURES C1 and C2, respectively. As expected, the initial values of ORP (or the values after response time was overcome) were increasingly greater for the samples which had undergone longer aeration times. However, the trend with testing time was not consistent as the ORP for a sample at the end of Pass 1 fell below that for a sample at the beginning of Pass 1 after less than 0.7 hour of testing.

The ultimate values of ORP for the return sludge were approximately the same in each case at E_h = -120 mv. to -155 mv. although the time taken to reach the ultimate varied. In fact, a sample taken at the end of Pass 2 still had not levelled to a constant ORP after three hours of testing.

For mixed liquor samples the ultimate ORP was about E_h = -215 mv., reached after two hours of testing by a sample from the end of Pass 3. The other samples' O-R potentials were still decreasing when the tests were terminated, but they appeared to be approaching the same equilibrium value around -215 mv.

ORP reduction rate curves of the secondary influent and

effluent of Tank 1 are shown in FIGURE C3. The slope of the effluent curve was particularly mild, falling only 15 mv. over a 2.5 hour period. The influent curve was also quite flat around -90 mv.

5.5.2 Various Operations

ORP reduction rate curves for the mixed liquor effluent, from Aeration Tank 3 under some different operating conditions, are presented in FIGURE C4. Shown are the results for increased hydraulic load, decreased aeration, and increased suspended solids operations.

The initial portion of the curve for increased hydraulic load was much more level than the others because the electrodes were placed in a buffered quinhydrone solution, prior to use, to reduce the electrode response times. This curve likely would have started above 400 mv. if it had not been for this deviation from the regular experimental procedure.

No significant variation was noted in the maximum slope for each curve; however, variations became greater with testing time.

Equilibrium values for each curve were not quite reached during the test periods but would appear to be between E_h = -160 mv. for decreased aeration and less than -200 mv. for increased hydraulic load.

5.5.3 Comparison with Nussberger's Results

The curves in FIGURES C1 and C4 are compared with those obtained by Nussberger (1953) in FIGURES 15 and 16, respectively.

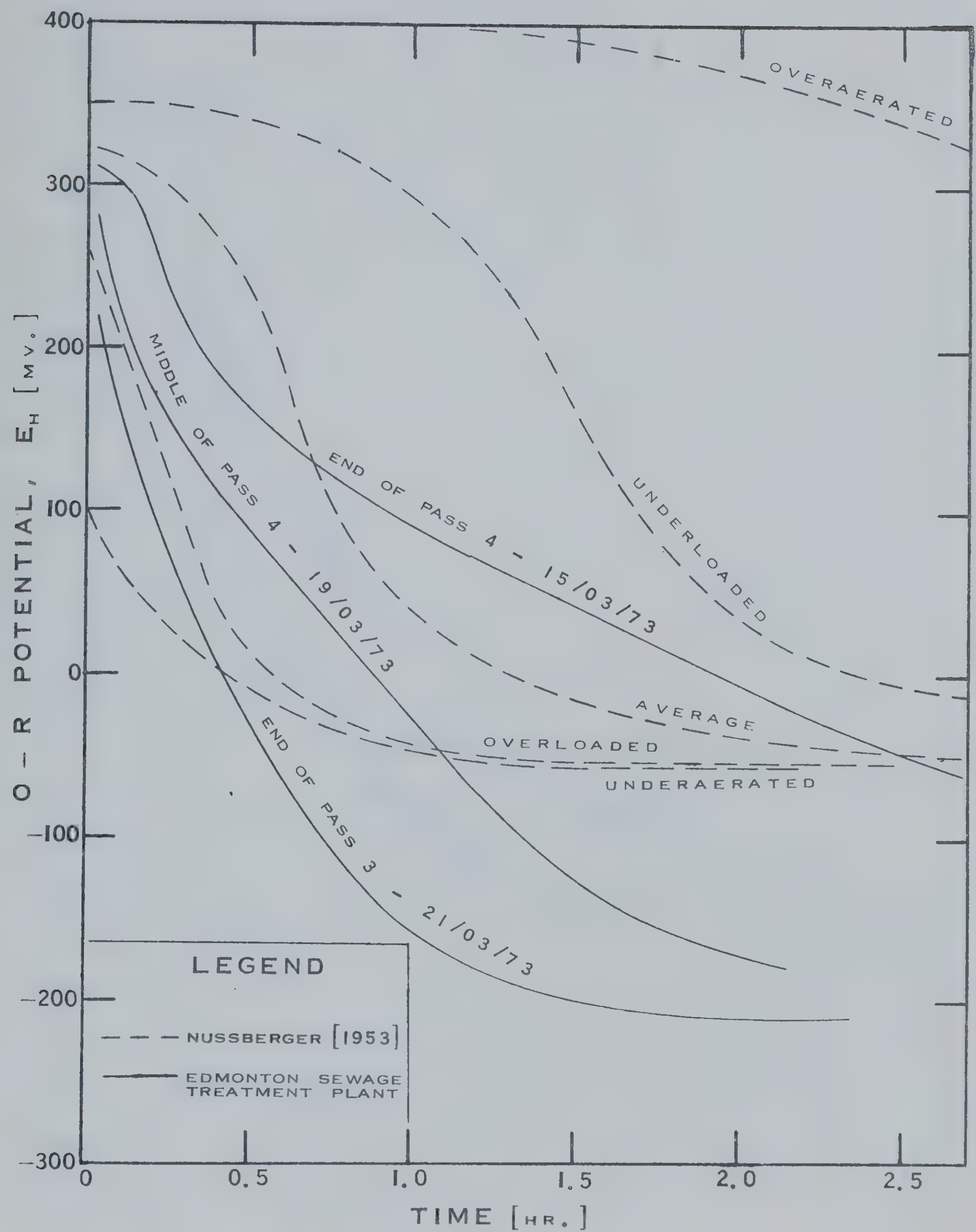


FIGURE 15: COMPARISON OF ORP REDUCTION RATE CURVES AT EDMONTON (FIGURE C1) WITH CURVES FOR NUSSBERGER (FIGURE 2)

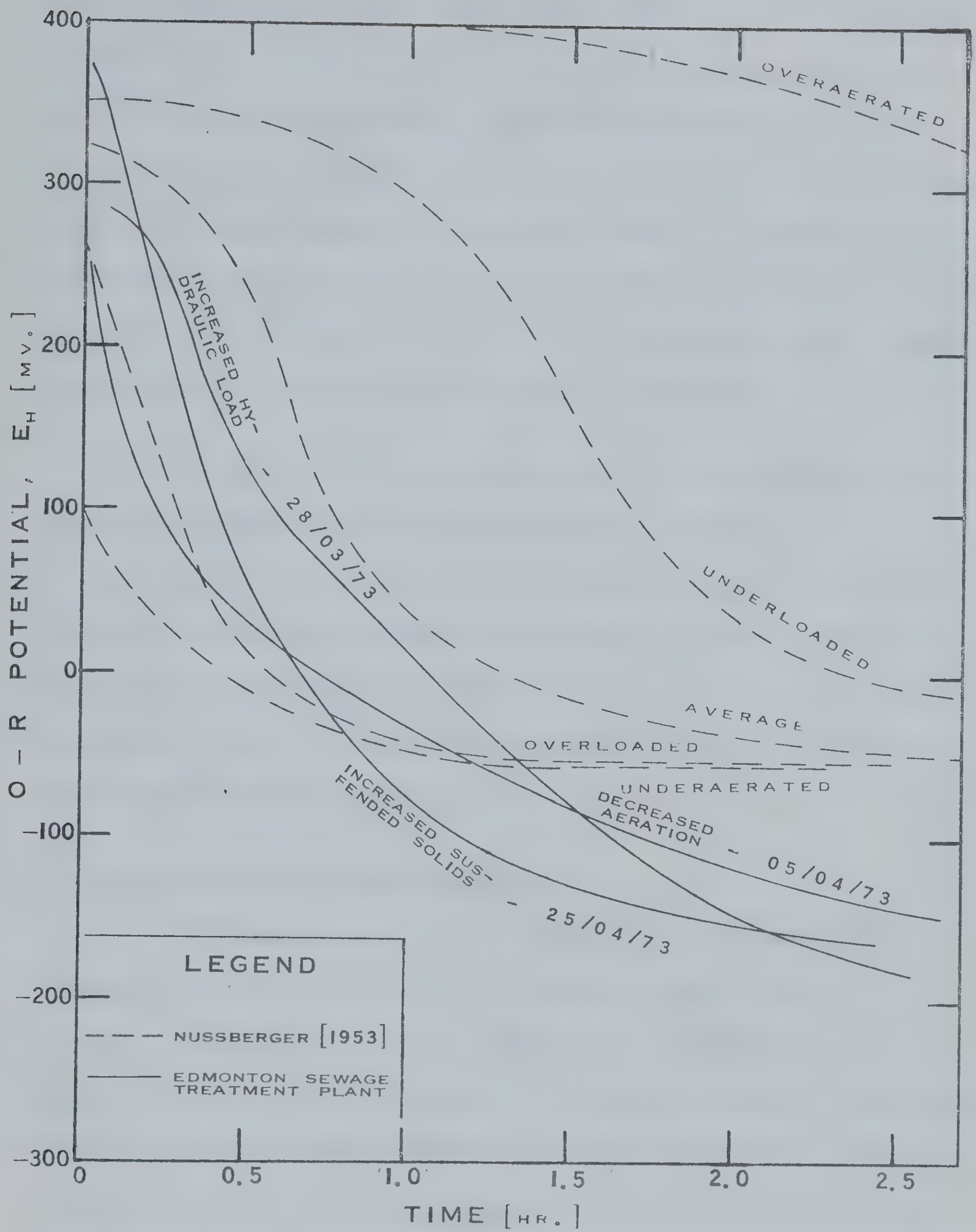


FIGURE 16: COMPARISON OF ORP REDUCTION RATE CURVES FOR EDMONTON (FIGURE C4) WITH CURVES BY NUSSBERGER (FIGURE 2)

For the mixed liquor samples from various locations it can be seen in FIGURE 15 that the sample from the end of Pass 4 agreed most closely with Nussberger's average curve, although the shapes of the curves were considerably different, the Edmonton curve having a more uniform slope. The sample from the half point of Pass 4 followed Nussberger's "overloaded" curve the closest while the sample from the start of Pass 4 fell below the "overloaded" curve. The ultimate ORP values at Edmonton were as much as 150 mv. lower than those by Nussberger.

The Edmonton curves obtained under various operating conditions are compared with Nussberger's curves in FIGURE 16. For increased hydraulic load and increased suspended solids the curves initially fell between Nussberger's "average" and "overloaded" curves; whereas for decreased aeration the curve was similar to Nussberger's "overloaded" curve. Again the final values of ORP were considerably lower than those found by Nussberger.

5.6 Comparison of ORP with Plant Data

To attempt to relate O-R potentials to overall secondary treatment efficiency, an analysis of the plant data was first necessary. The BOD of the final effluent was considered for this purpose to be a reliable indication of the effectiveness of operations on a given day. To avoid problems which might have arisen from daily variations in aeration tank loadings, the test aeration tank (3) and the control tanks (1, 2, 4, and 5) were compared only on a daily basis as in FIGURE 17, rather than with long term averages.

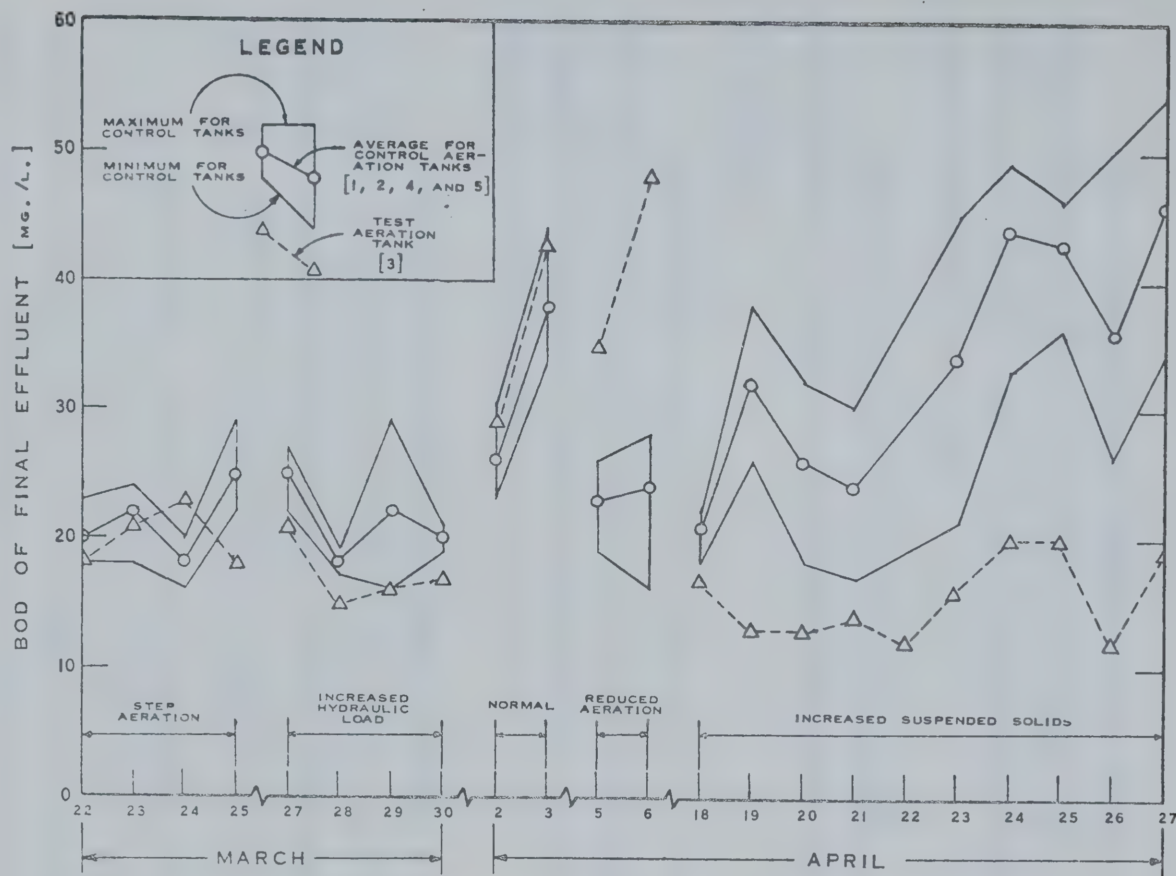


FIGURE 17: COMPARISON OF FINAL EFFLUENT BOD FOR AERATION TANK 3 UNDER VARIOUS OPERATING CONDITIONS WITH THAT FOR AERATION TANKS 1, 2, 4, AND 5 UNDER NORMAL OPERATION - EDMONTON SEWAGE TREATMENT PLANT, 1973

For step aeration operation of Tank 3, no appreciable difference in treatment was observed.

For increased hydraulic loading on Tank 3, better treatment than the average for the other tanks was obtained during four days of testing. Only on one of those days did the performance of one of the control tanks match that of Tank 3.

During a two-day period in which Tank 3 operated normally (same as Tanks 1, 2, 4 and 5), no appreciable difference in performance was observed.

During another two-day period, a 25% aeration rate reduction for Tank 3 was found to have a drastic effect on its performance, increasing the final effluent BOD by as much as 22 mg./l. above that for the worst of the control tanks.

For increased suspended solids operation of Tank 3, performance was superior to that of any of the control tanks over a ten-day period. During that time the final effluent BOD for Tank 3 never exceeded 20 mg./l. while that for the control tanks was as high as 54 mg./l.

From the data it can be seen that good treatment was obtained when minimum O-R potentials were as low as 150 mv. and average potentials about 200 mv., poor treatment was obtained when minimum potentials were around 100 mv. and average potentials 125 mv. At potentials above 150 mv. there was no noticeable relationship between ORP and quality of treatment. The data may be somewhat

limiting because the effect of time, in which borderline O-R potentials (150 mv.) could be maintained, was not evaluated.

With regard to dissolved oxygen concentrations, it is observed that good treatment was accomplished even when tank DO values were very low. The actual DO values existing were not determined precisely because of the large errors inherent in measuring low DO concentration with the thallium probe. The minimum tank DO at which good treatment was obtained was somewhere between 0.1 and 0.7 mg./1.

5.7 Summary

Good results were obtained for ORP profiles of the aeration tanks under a variety of operating conditions. An understanding of the effects of some of these conditions was supported by DO profiles, ORP reduction rate data, and plant performance data.

Operations investigated in addition to the normal included step aeration, increased hydraulic load, reduced aeration, and increased suspended solids. ORP profile data gave no reiable indication of overall treatment efficiency except for the reduced aeration condition in which potentials were substantially lower than for the others, and the quality of treatment deteriorated significantly.

Dissolved oxygen data could not be directly correlated with ORP data. However, it was generally observed that when ORP values increased, so did DO values and vice versa. The relationship was far from linear as the change in DO for a given change in ORP was much greater at high values of ORP than at low ones. Also, since ORP and

DO data was not directly correlated, various values of ORP were observed for a given DO, particularly at higher DO concentrations.

ORP reduction rate tests indicated that aeration tank samples were more resistant to changes in potential with time as the aeration periods increased. Poor comparison of the curves, with those of Nussberger (1953) was found with regard to the initial slopes and the ultimate potentials reached.

CHAPTER VI

CONCLUSIONS

6.1 Review of Study

Before conclusions are formulated, a brief review of the ORP study would be valuable. The main objective of the study was to determine whether or not ORP measurements could provide a reliable indication of satisfactory aeration tank conditions. Various operating conditions were therefore investigated for this purpose and to discover possible superior operations.

The general approach to the investigation began with a literature review of O-R potentials. A wide range of information was covered in the review with the theoretical importance of ORP measurements being particularly stressed. It was seen that they could provide valuable information regarding the state of a biological system because they could indicate the degree of oxidation which did not depend solely on dissolved oxygen. It was recommended by a few investigators that aeration tank conditions never fall below +100 mv. (E_h) to ensure suitable conditions for the growth of aerobic organisms.

To obtain a proper perspective of the study, the Edmonton Sewage Treatment Plant was described along with some theory upon

which its secondary treatment process was based: the activated sludge process. The Edmonton Plant resembled various modifications of this process, the most predominant of which was contact stabilization.

The above introductory information was followed by a detailed account of the study which included a description of the equipment used, the procedures followed, and the results obtained. A special ORP field kit was designed for in situ measurements because of problems associated with measurements on grab samples. Readings were taken with four home-made platinum measuring electrodes in conjunction with a saturated calomel reference electrode. Field measurements focussed on profiles of the aeration tanks, one which was operated under a wide variety of conditions and the others which were operated normally to provide a basis for comparison. DO profiles were taken to compare with ORP profiles and to give extra insight for interpretation of ORP results. ORP reduction rate measurements on grab samples were also performed to determine the effects of removing contact of air with sewage samples.

The results of the investigation provided sufficient information to enable conclusions to be formulated. The effects of different tank operating procedures were clearly indicated by the ORP profiles, whereas effects on DO profiles were not so noticeable, particularly at low DO concentrations. Also no clear relationship existed between ORP and DO values, although the two increased and decreased simultaneously in a given profile. Satisfactory aeration tank operations existed when O-R potentials were maintained above 150 mv. (E_h) and unsatisfactory conditions resulted when potentials fell to 100 mv.

Through the course of investigating various operating conditions, it was also shown that significant improvements in treatment could be realized; however, ORP measurements seemed to provide no indication of the higher efficiencies achieved, only the lower efficiencies associated with insufficient aeration.

6.2 Significance of ORP in Aeration Tanks

Regarding the main objective of the study, it was found that ORP measurements can give a good indication of satisfactory aeration tank conditions only with regard to adequacy of aeration. The measurements are particularly valuable, in place of DO determinations, when DO concentrations are low. Since it was shown that excellent BOD removals can be attained (FIGURE 17) even when DO concentrations over most of the tanks are approximately 0.5 mg./l. (FIGURE B3), the value of ORP measurements is further enhanced because DO determinations with probes are highly inaccurate at such low values.

ORP measurements provide information regarding the state of oxidation of a biological system, whereas DO measurements do not. These conclusions are based on the observation that ORP and DO values are not directly related as shown in FIGURE 14. Return sludge that has undergone much longer periods of aeration than mixed liquor, has a substantially higher ORP which appears to be indicative of the degree of sludge stabilization. DO values provide no such information since poorly stabilized sludge can exhibit a high DO (if aeration rates are great enough).

Some doubt exists whether or not ORP measurements are actually indicative of the state of health of a biological system as claimed by some investigators. Rather, it might be said that they indicate if conditions are not suitable for the growth of particular organisms. This is stated in a negative manner because optimum ORP conditions do not necessarily result in optimum growth, but low ORP conditions would cause poor growth. This seemed to be demonstrated in the reduced aeration condition for which lower potentials reflected poor BOD removal, while for higher ORP conditions the magnitude of the potential did not seem to influence the BOD removal. Factors other than ORP, such as quantities and types of nutrients and nutrient-organism ratios, certainly are important. These effects of these factors were not isolated in profile measurements but possibly could explain some of the observed differences in reduction rate measurements. The author does not wish to hazard any further guesses regarding this, but only to suggest that further work would be necessary to determine the various factors involved and the significance of each.

6.3 Comparison of Operating Conditions

Various operating conditions result in characteristic ORP profiles. For a given aeration rate, the main factor determining the shape of the ORP curve is the sewage addition point(s). If the sewage is added over a considerable portion of a tank instead of being concentrated in one area, a general flattening of the curve results. This was observed for step aeration and increased hydraulic load operating conditions as shown in FIGURES A2 and A3. If the

sewage is added at one point or several points close together, wide fluctuations in the curve results. This was observed for normal and increased suspended solids operations. However, if the return sludge is at a low ORP before sewage is added, the ORP curve shows little fluctuation as was observed for the reduced aeration operating condition. The relative magnitudes of the return sludge and secondary sewage influent ORP also affect the shape of the ORP profile.

Detailed explanations of the merits of different operating conditions are considered beyond the scope of this thesis. However, a few thoughts would be appropriate for an overall understanding of the situation. More data is required to determine if step aeration is better or worse than the normal operating procedure at Edmonton. For increased hydraulic load, the operation is definitely better although the reasons are uncertain. Possibly the aeration tanks are presently underloaded so that nutrient supply is a controlling factor, or possibly the shorter aeration times for the return sludge (5 hours for increased load as compared to 19 hours for normal load) lessen bacterial enzyme production due to nutrient depletion associated with long sludge stabilization periods. The best operating procedure of those investigated is definitely that for increased suspended solids as seen in FIGURE 17. Better treatment can be obtained through this change because sufficient suspended solids are available to adsorb more of the applied organic material. The low suspended solids for normal operation, therefore, is one factor limiting BOD removals.

6.4 ORP Reduction Rates

The value of ORP reduction rate measurements is doubtful because they are not accurately reproducible. Reproducibility is adversely affected mainly because the rate and magnitude of temperature change in the sample during measurement is uncontrollable if the author's procedure is followed. A constant temperature bath would be required to rectify this problem.

The reduction rate curves obtained by Nussberger (1953) do not resemble the curves for Edmonton very closely. Initial and final ORP values as well as the slopes of the curves are quite different (FIGURE 15 and FIGURE 16). Misinterpretation of results would occur if Nussberger's curves were used as a basis of comparison with the Edmonton curves. To illustrate this point, the Edmonton curve for increased suspended solids, despite being associated with good treatment, resembles Nussberger's overloaded curve more closely than any of his other curves. Different electrode behavior could possibly be one explanation. Nussberger used only one platinum electrode in his experiments so that his results could be considerably in error. The observed differences could also be due to different characteristics of the samples.

The value of ORP reduction rate measurements in comparing different operations is doubtful. As shown in FIGURE C4, only small differences in curves occurred for three greatly different operations. In comparing results for different locations, as in FIGURE C1, the considerable spread of results for mixed liquor samples possibly indicates

that the test may be of some value in distinguishing between under-aerated and overaerated conditions which are characteristic of short and long aeration periods, respectively.

6.5 Questionable Operating Procedures

Some questionable points with regard to normal secondary operation arose as a result of the ORP study.

First, the method of controlling aeration rates in the aeration tanks appears to be wasteful of energy. Aeration rates are changed as required over the entire length of each aeration tank where the DO reading for one probe at the end of any one tank is not in the desired 2.0 to 4.0 mg./l. range. Consequently, aeration rates for the return sludge are increased when not required and conversely, aeration rates for the return sludge are not changed as and when required. Modification of aeration rate control devices to allow separate adjustment of aeration rates for different portions of each tank would be beneficial economically. Of course this would necessitate additional monitoring equipment to inform the plant operator when a change is required.

Secondly, sludge in the final settling tanks is detained longer than necessary because it is collected at the far ends rather than the near ends before returning to the aeration tanks. This results in an extra decrease in ORP and additional deterioration of the sludge. This does not appear to be a significant problem at Edmonton; however, if the tanks operated more closely to their maximum capabilities, excessive sludge deterioration might result.

Thirdly, the return sludge is normally aerated for much longer time periods than suggested in the literature (TABLE V). This possibly explains the lower BOD removal efficiencies obtained at Edmonton than at other plants. Return sludge rates could be increased or sewage added sooner to rectify the situation.

Fourthly, there is presently insufficient data to provide adequate control and analysis of aeration tank performance. Aeration rate and individual tank flow rate recorders are especially necessary in this regard.

6.6 Recommendations

Since the value of ORP measurements in providing useful information regarding aeration tank conditions has been demonstrated, it would appear desirable that further research be directed towards ORP monitoring of tank conditions for the purpose of aeration control. Direct and associated problems of this recommendation should be investigated as follows:

1. The reliability of platinum electrodes during continuous monitoring of aeration tank conditions should be established.
2. The frequency of required cleaning of electrodes which are used for monitoring should be determined. If this is proven to be excessive, then continuous, automatic cleaning methods should be investigated.
3. The optimum ORP range for satisfactory aeration tank performance should be established more closely.

4. The minimum number of measurements and their locations, necessary for good aeration control, should be established.
5. The effect of dissolved oxygen on ORP should be determined more accurately by using simultaneous DO-ORP measurements under a wide variety of conditions.
6. The effects of other factors on ORP, and possibly ORP reduction rates, should be isolated to give a more meaningful understanding of the measurement.

LIST OF REFERENCES

Backmeyer, D. P. and Drautz, K.E., 1961, "ORP and Operation," WPCF Journal, v. 33, p. 906.

Bargman, R. D. et al., 1957, "Aeration Requirements of a High Oxygen Demand Sewage," Sewage and Industrial Wastes, v. 29, p. 768.

Brock, T. D., 1970, Biology of Microorganisms, Prentice -Hall Inc., Englewood Cliffs, New Jersey

Dirasian, H. A.; 1968, "Electrode Potentials - Significance in Biological Systems, Part 1: Fundamentals of Measurement, Part 2: Experiences in Waste Treatment, Part 3: Sludge Digestion," Water and Sewage Works; v. 115, p. 420, 453, 505.

Eckenfelder, W. W., Jr., and Hood, J. W., 1951, Proc. of Sixth Industrial Waste Conference, Purdue University, p. 221

Eckenfelder, W. W., Jr., and O'Connor, D. J., 1961, Biological Waste Treatment, Pergamon Press, New York

Eliassen and Rolf, 1945, Water and Sewage Works - Ref. and Data Edition, p. 211

Fair, G. M., Geyer, J. C., and Okun, D. A., 1968, Water Purification and Wastewater Treatment and Disposal, John Wiley and Sons Inc., New York, v. 2.

Fisher, R. B., and Peters, D. G., 1968, Quantitative Chemical Analysis, W. B. Saunders Company, Toronto

Goodman, B. L., 1971, Manual for Activated Sludge Sewage Treatment, Technomic Publishing Company, Westport, Conn.

LIST OF REFERENCES
(Continued)

Grune, W. N., and Lotze, T. H., 1958, "Redox Potentials in Sludge Digestion," Water and Sewage Works, v. 105, p. 37.

Hartz, K. E., and Korentz, R. R., 1966, "Effects of CO_2 and N_2 on Anaerobic Digestion," Proc. ASCE, Sanitary Engineering Div., v. 92, p. 83.

Haseltine, T. R., 1961, "Sludge Reaeration in the Activated Sludge Process - A Survey," WPCF Journal, v. 33, p. 946.

Henry, C. R., Aug. 1960, "Measuring the ORP of Sewage," WPCF Journal, v. 32, p. 897.

Henry, C. R., Dec. 1960, "ORP for Sewage Plant Control from Raw Sewage to Effluent," Wastes Engineering, p. 722.

Henry, C. R., 1973, Personal communication.

Hewitt, L. F., 1950, Oxidation - Reduction Potential in Bacteriology and Biochemistry, Sixth Edition, E. S. Lewiston Ltd., Edinburgh.

Hood, J. W., 1948, "Measurement and Control of Sewage Treatment Process Efficiency by Oxidation - Reduction Potential," Sewage Works Journal, v. 20, p. 640.

Hood, J. W., and Rolich, G. A., 1959, "Oxidation - Reduction Potentials in Sewage Treatment," Water and Sewage Works, v. 96, p. 352.

Molof, A. H., 1961, A Study of Oxidation - Reduction Potentials applied to Sewage Sludge Digestion, PhD. Thesis, University of Michigan.

Moore, W. A. et al., 1942, "Oxidation - Reduction Studies I. Oxidation - Reduction Potentials Developed by Pure Cultures in Sewage," Sewage Works Journal, v. 14, p. 980.

LIST OF REFERENCES
(Continued)

Natarajan, K. A., and Iwasaki, I., 1970, "Behavior of Platinum Electrodes as Redox Potential Indicators in Some Systems of Metallurgical Interest," Transactions, Society of Mining Engineers, AIME, v. 247, p. 317.

Nussberger, F. E., 1953, "Application of Oxidation - Reduction Potentials to the Control of Sewage Treatment Processes," Sewage and Industrial Wastes, v. 25, p. 1003.

Okey, R. W. et al, 1946, "Growth and Oxidation Kinetics in Mixed Microbial Systems as a Function of Oxidation - Reduction Potential," Developments in Industrial Microbiology, v. 4, p. 223.

O'Rourke, J. T. et al, 1964, "Variation of ORP in an Activated Sludge Plant with Industrial Waste Load," Canadian Municipal Utilities, May, p. 44.

Rich, L. G., 1963, Unit Processes of Sanitary Engineering, John Wiley and Sons Inc., New York

Rohlich, G. A., 1948, Discussion - "Measurement and Control of Sewage Treatment Process Efficiency by Oxidation - Reduction Potential," (by Hood, J. W.), Sewage Works Journal, v. 20, p. 640.

APPENDIX A

ORP PROFILES OF AERATION TANKS AT THE EDMONTON SEWAGE TREATMENT PLANT

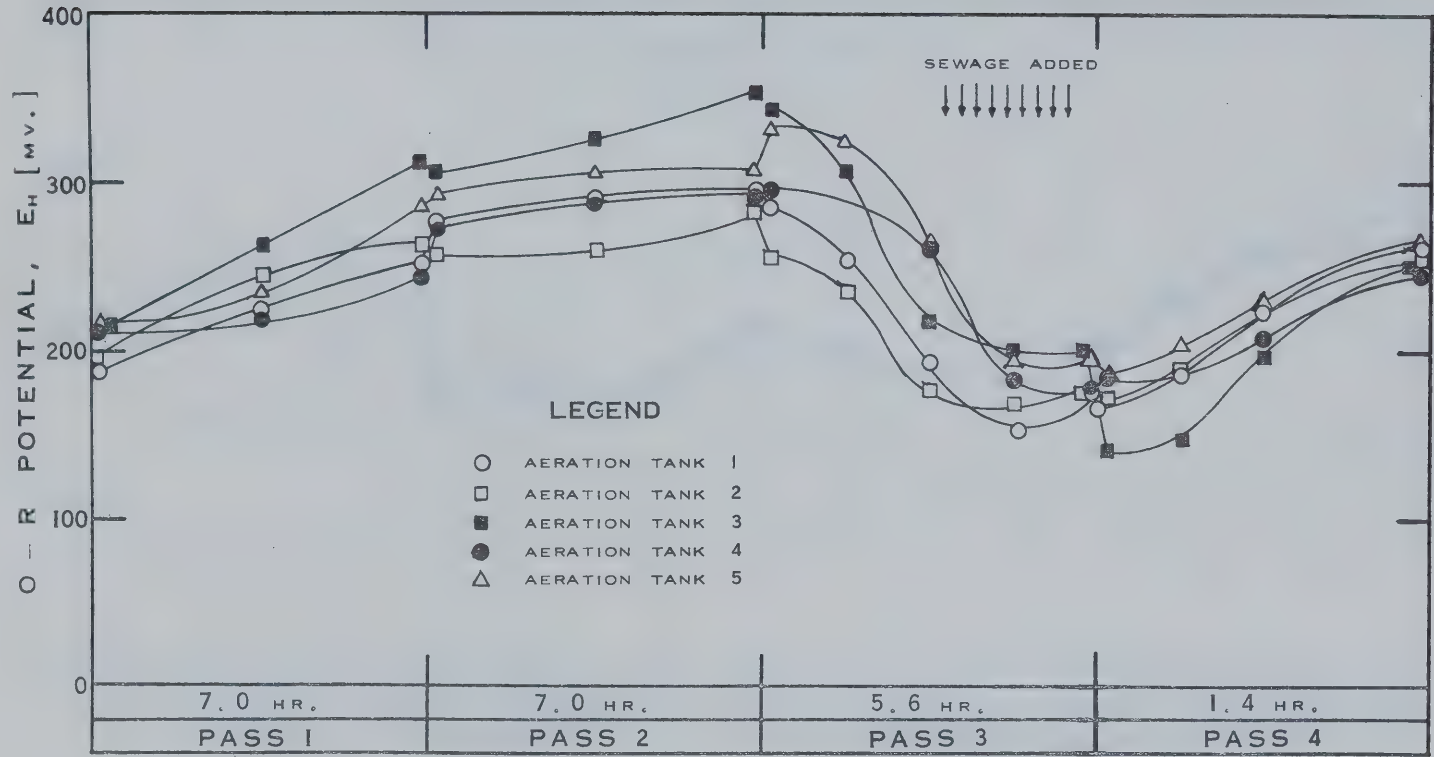


FIGURE A1: ORP PROFILES OF AERATION TANKS 1 TO 5, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

[a] Supplementary data is contained in TABLES D1 and E1.

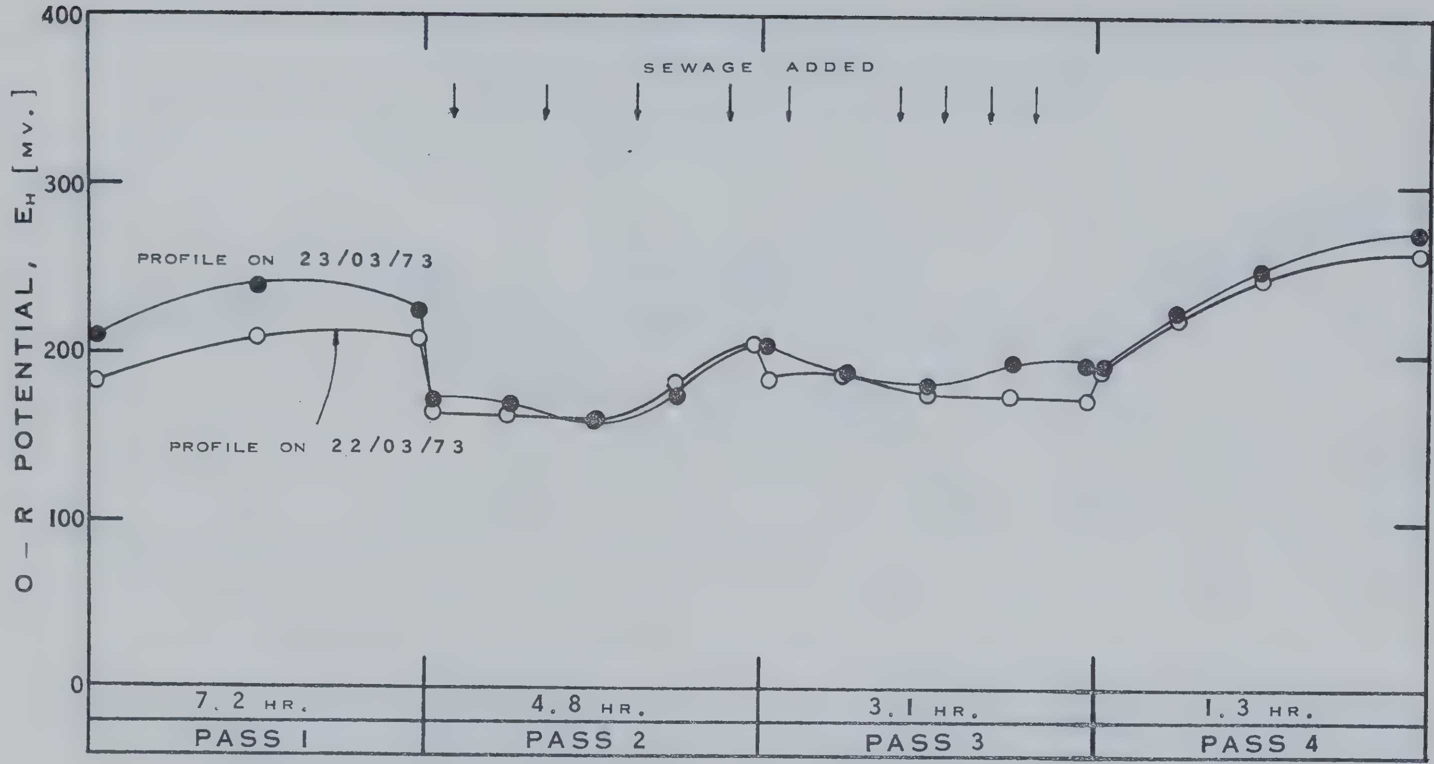


FIGURE A2: ORP PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - STEP AERATION OVER PASSES 2 AND 3[a]

[a] Supplementary data is contained in TABLES D2 and E2.

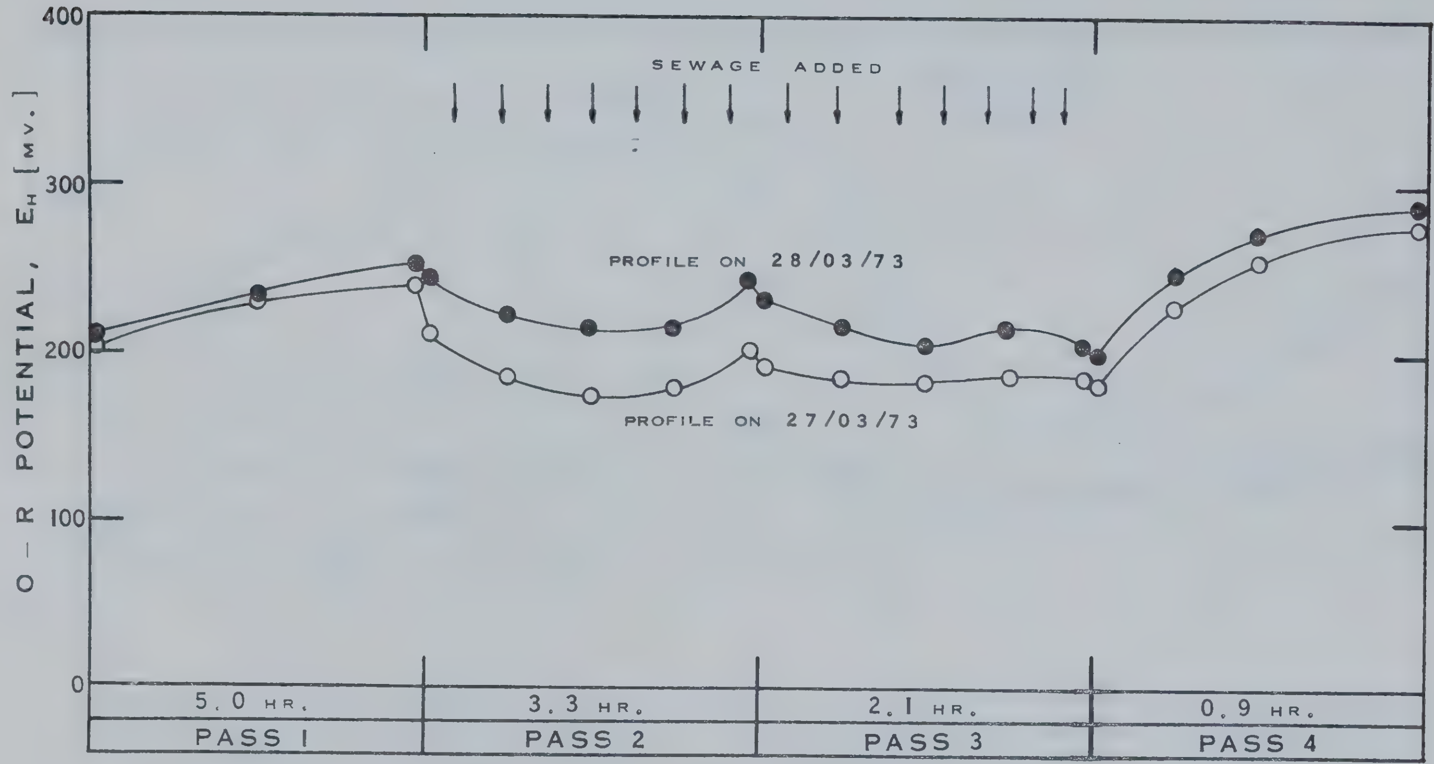


FIGURE A3: ORP PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - INCREASED HYDRAULIC LOAD[a]

[a] Supplementary data is contained in TABLES D2 and E2. Note that aeration and return sludge rates were also increased.

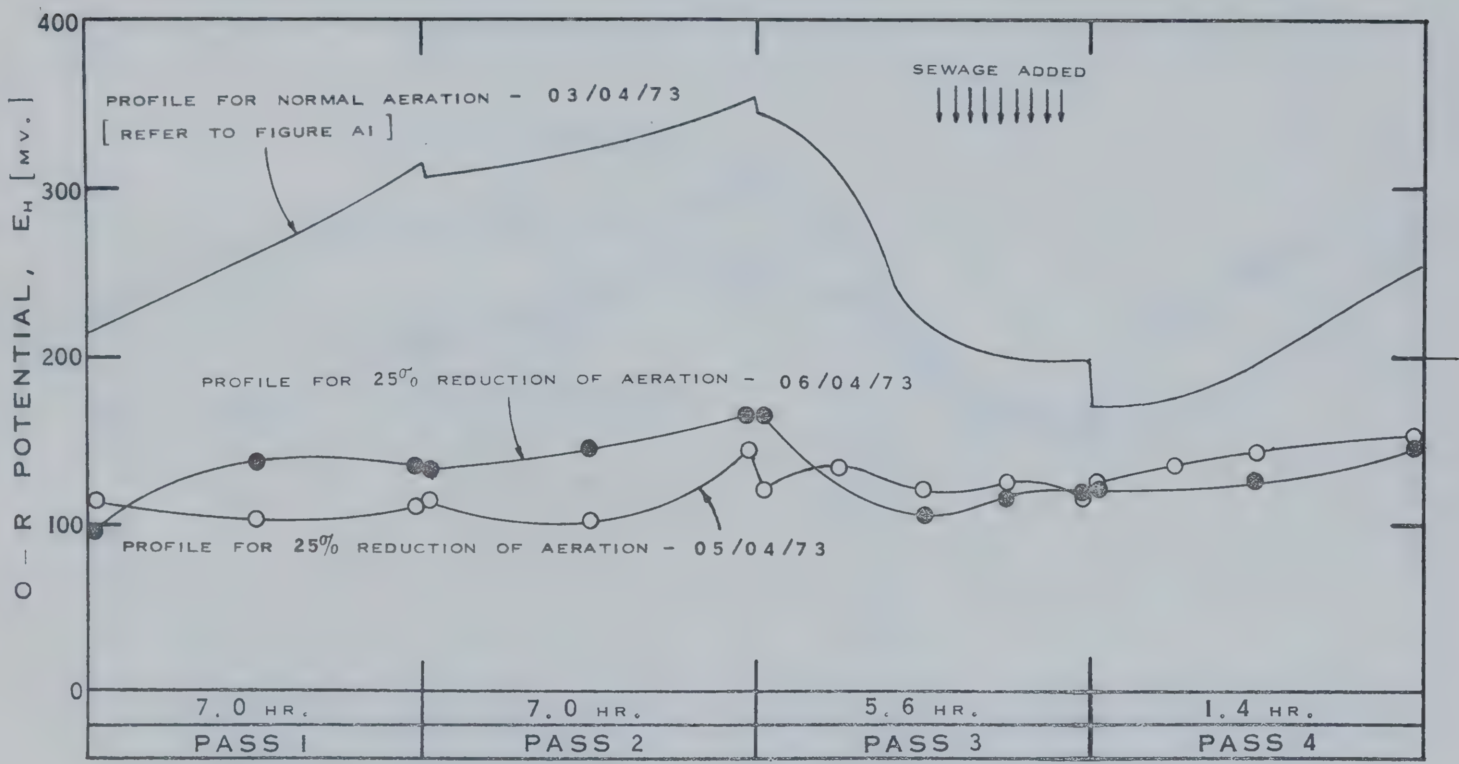


FIGURE A4: ORP PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - DIFFERENT AERATION RATES[a]

[a] Supplementary data is contained in TABLES D2 and E2.

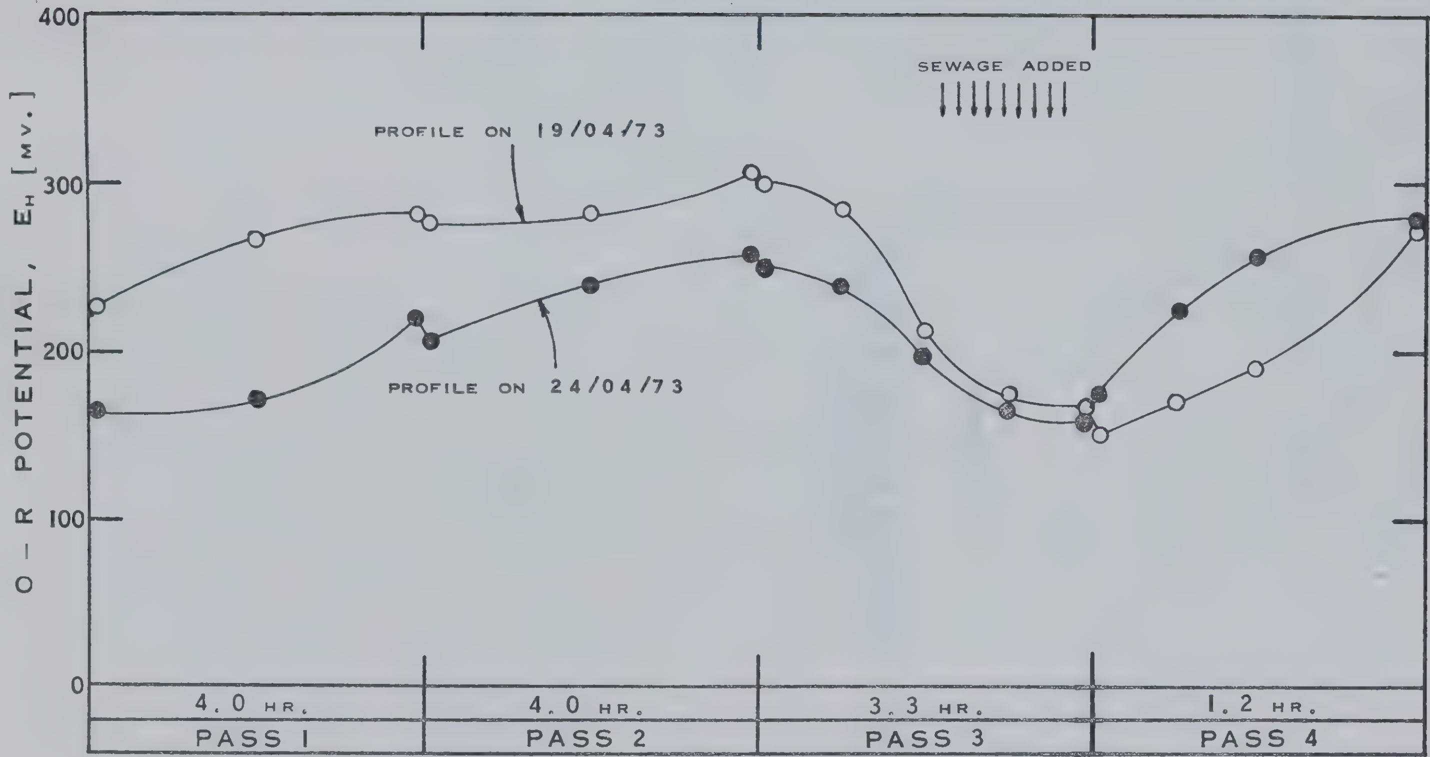


FIGURE A5: ORP PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - INCREASED SUSPENDED SOLIDS IN RETURN SLUDGE AND MIXED LIQUOR[a]

[a] Supplementary data is contained in TABLES D2 and E2. Note that aeration and return sludge rates were also increased.

APPENDIX B

ORP AND DO PROFILES OF AERATION TANKS AT THE EDMONTON SEWAGE TREATMENT PLANT

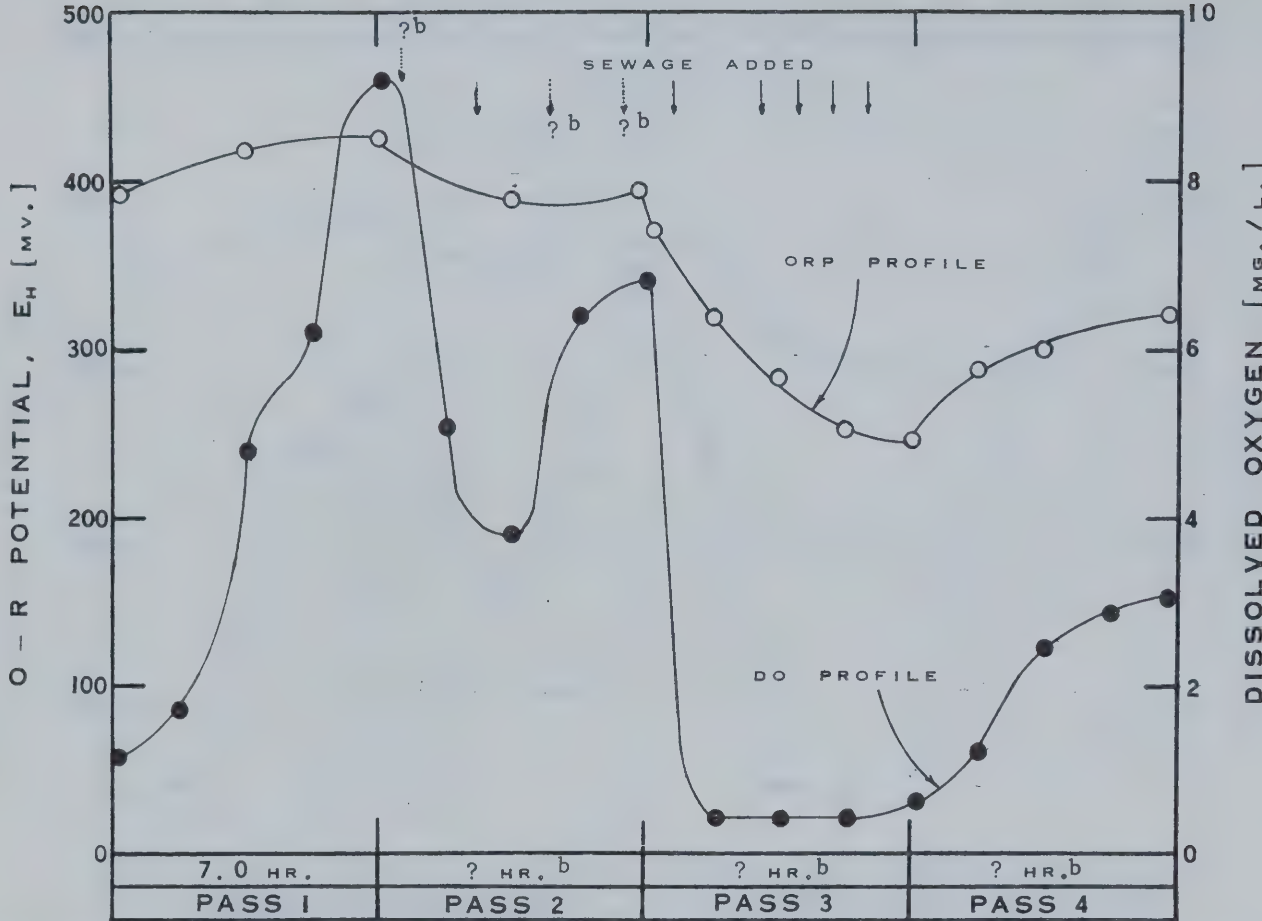


FIGURE B1: ORP AND DO PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - MARCH 12, 1973[a]

[a] Supplementary data is contained in TABLES D4 and E2.

[b] Magnitude of sewage influent flow rate was uncertain because influent gates were partially plugged and, as a result, detention times in Passes 2 to 4 could not be estimated.

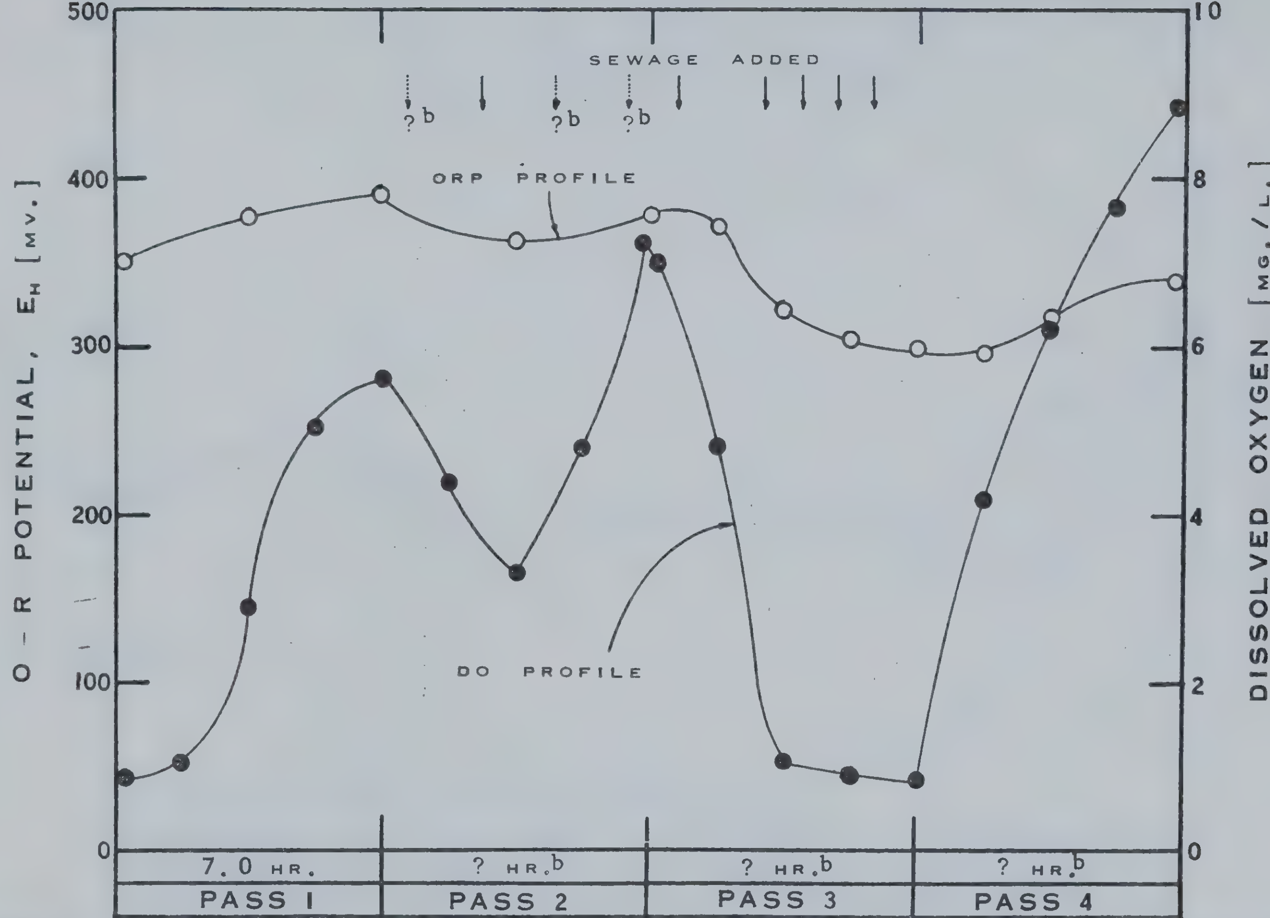


FIGURE B2: ORP AND DO PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - MARCH 14, 1973[a]

[a] Supplementary data is contained in TABLES D4 and E2.

[b] Magnitude of sewage influent flow rate was uncertain because influent gates were partially plugged and, as a result, detention times in Passes 2 to 4 could not be estimated.

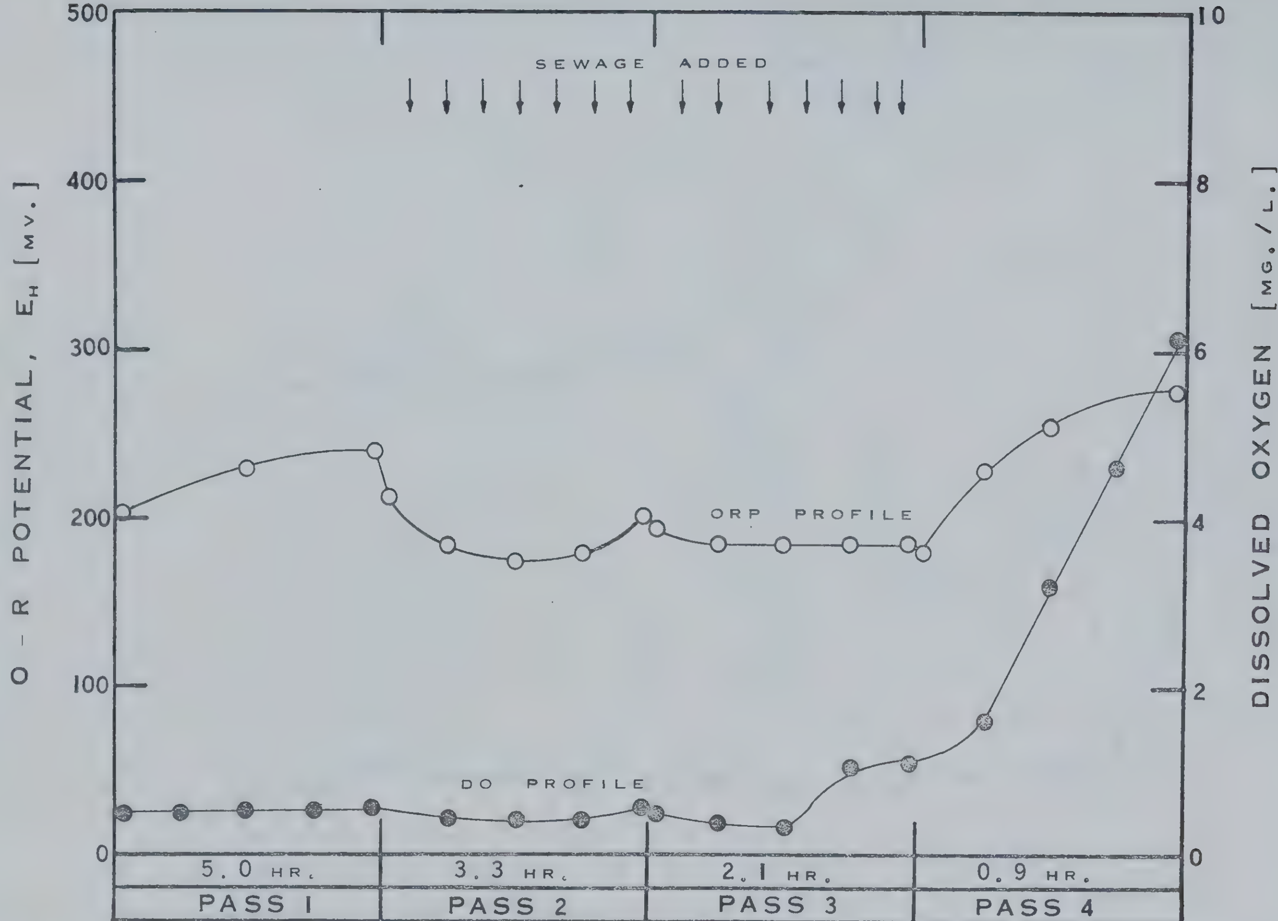


FIGURE B3: ORP AND DO PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - MARCH 27, 1973[a]

[a] Supplementary data is contained in TABLES D4 and E2.

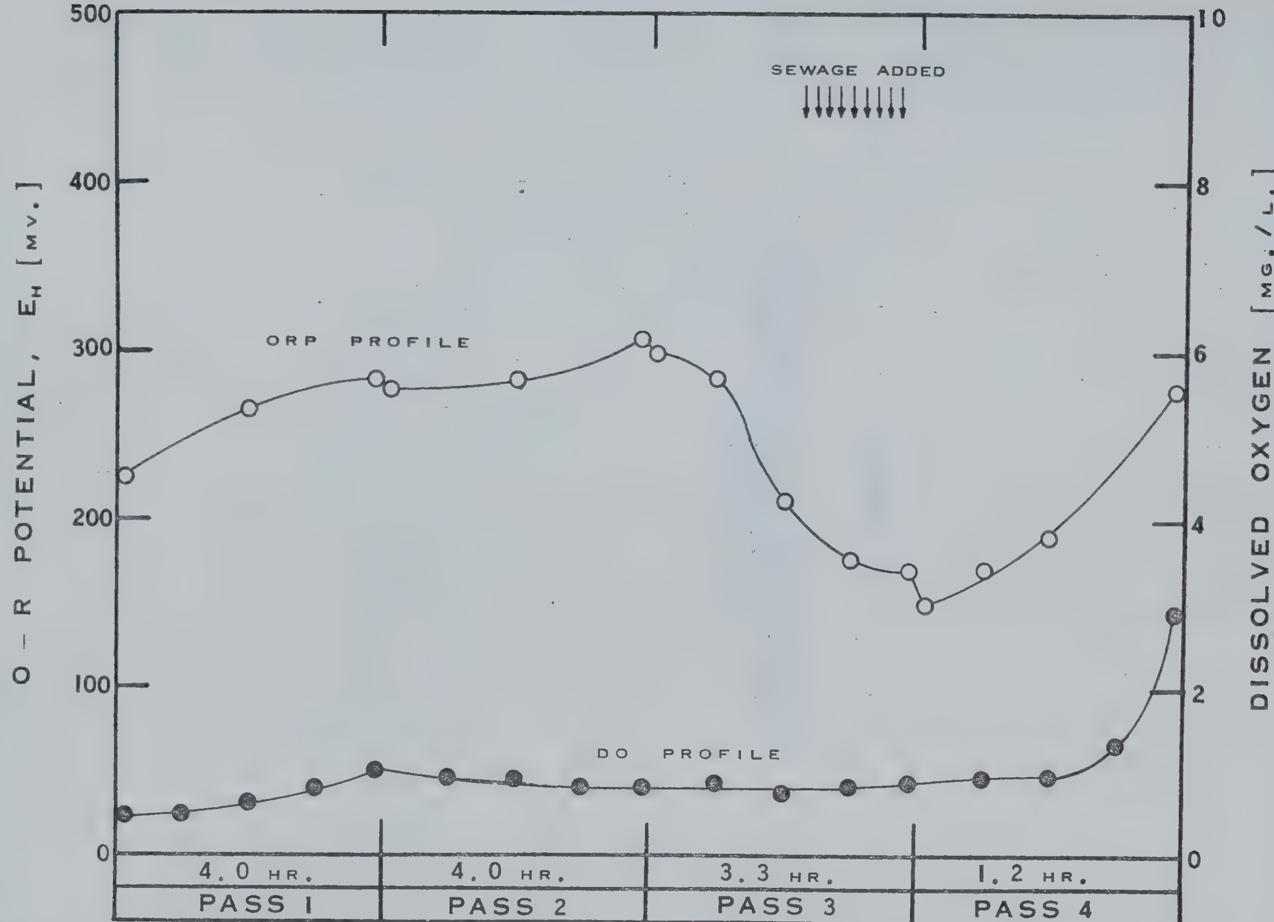


FIGURE B4: ORP AND DO PROFILES OF AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - APRIL 19/73[a]

[a] Supplementary data is contained in TABLES D4 and E2.

APPENDIX C

ORP REDUCTION RATE CURVES OF SEWAGE SAMPLES FROM THE EDMONTON SEWAGE TREATMENT PLANT

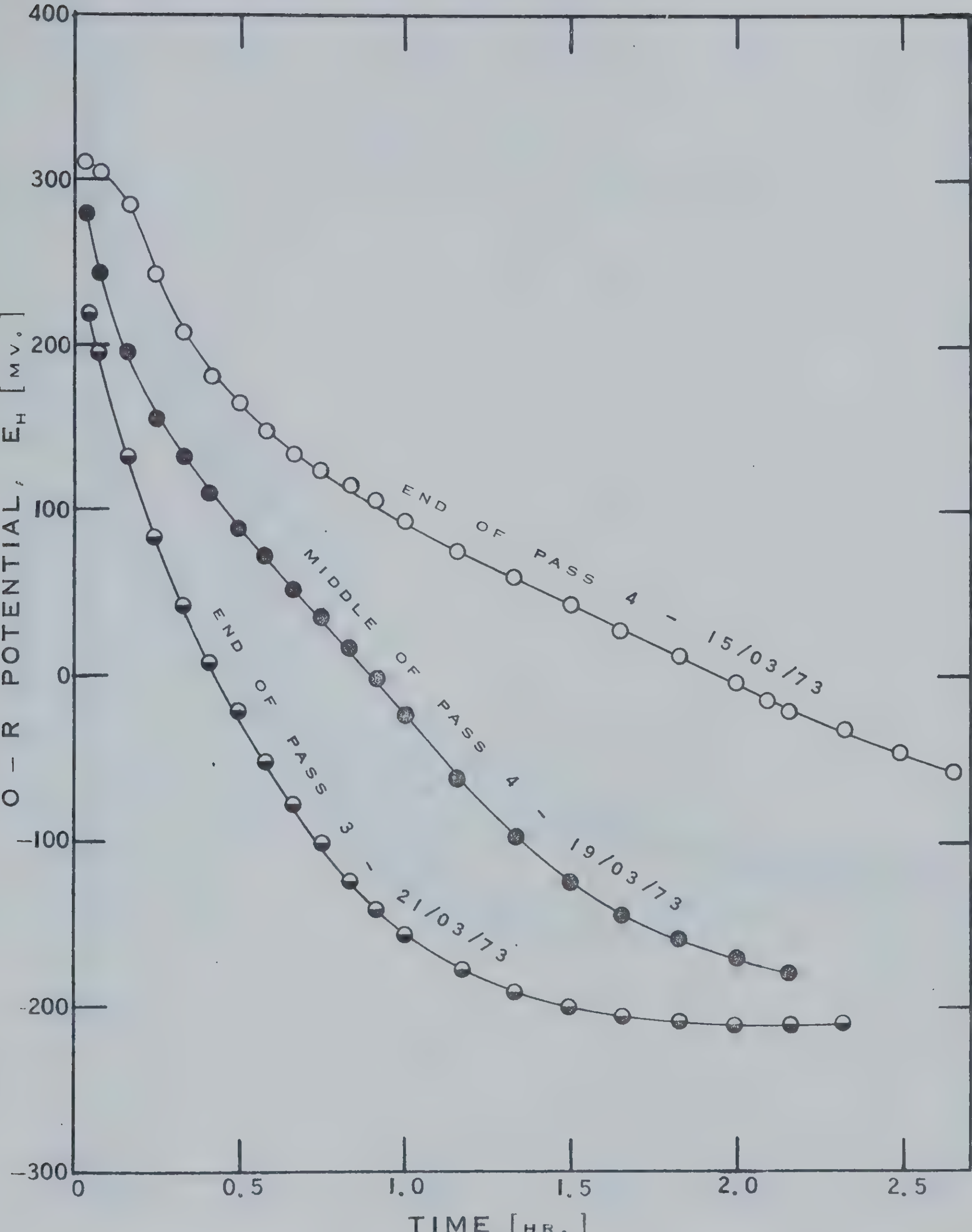


FIGURE C1: ORP REDUCTION RATE CURVES FOR MIXED LIQUOR FROM VARIOUS LOCATIONS ALONG AERATION TANK 1, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

[a] Supplementary data is contained in TABLE E1.

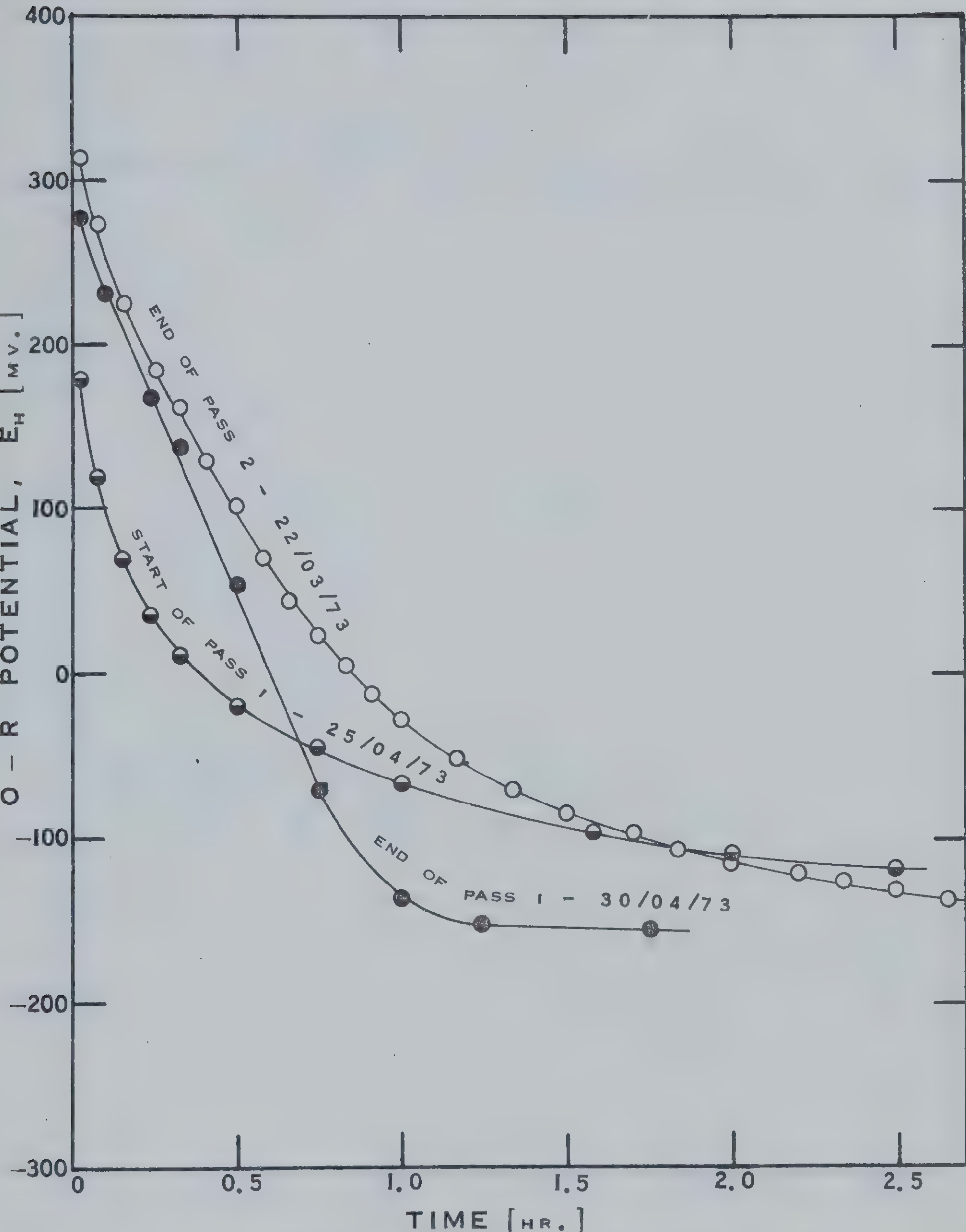


FIGURE C2: ORP REDUCTION RATE CURVES FOR RETURN SLUDGE FROM VARIOUS LOCATIONS ALONG AERATION TANK 1, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

[a] Supplementary data is contained in TABLE E1.

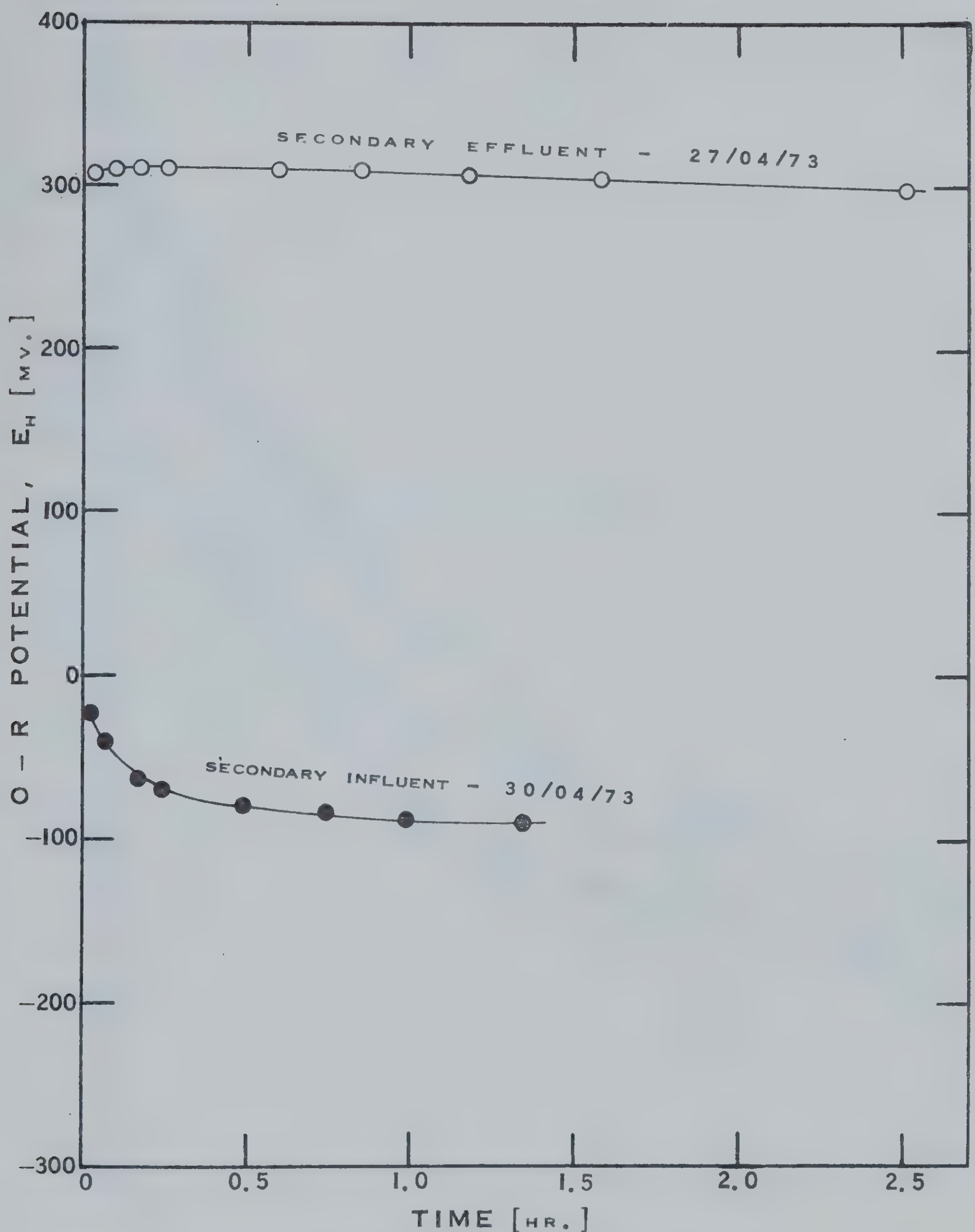


FIGURE C3: ORP REDUCTION RATE CURVES FOR INFLUENT TO AERATION TANK 1 AND EFFLUENT FROM FINAL SETTLING TANK 1, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

[a] Supplementary data is contained in TABLE E1.

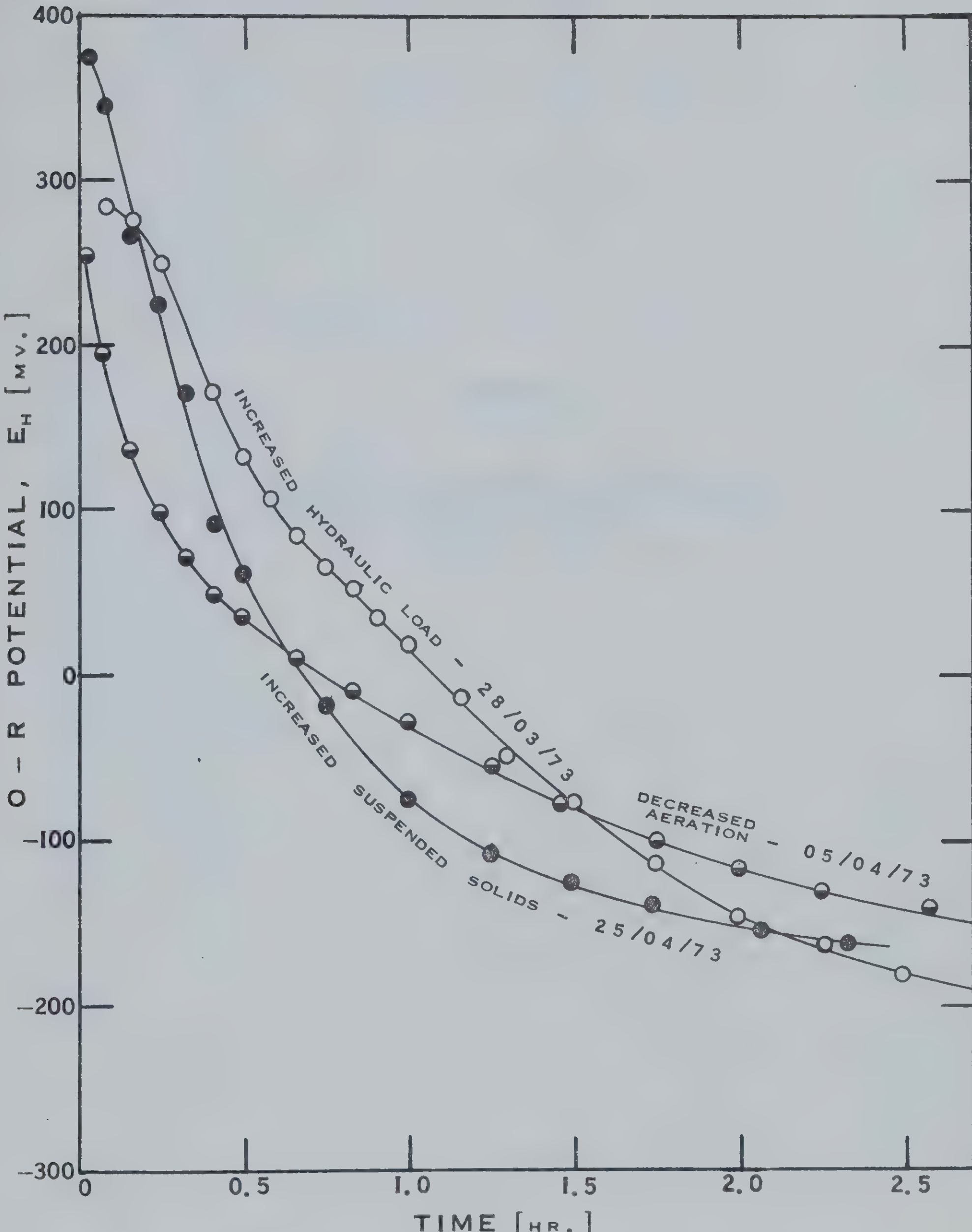


FIGURE C4: ORP REDUCTION RATE CURVES FOR MIXED LIQUOR EFFLUENT FROM AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - VARIOUS OPERATING CONDITIONS[a]

[a] Supplementary data is contained in TABLE E2.

APPENDIX D

ORP AND DO PROFILE DATA FOR AERATION TANKS AT THE EDMONTON SEWAGE TREATMENT PLANT

TABLE D1: ORP PROFILE DATA FOR AERATION TANKS 1 TO 5, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION[a]

	Aeration Tank - Date (d/m/y)											
	Tank 1 - 30/03/73		Tank 2 - 30/03/73		Tank 3 - 03/04/73		Tank 4 - 29/03/73		Tank 5 - 29/03/73		Average for Tanks 1 to 5	
Location[b]	E_h[c]	s[d]	E_h	s	E_h	s	E_h	s	E_h	s	E_h	s[f]
SI	15[e]	12[e]	-46[e]	8[e]	22	9	31	16	-54[e]	9[e]	-6	40
P1-0.00	186	12	197	9	215	1	212	9	214[e]	5[e]	205	13
P1-0.50	223[e]	2[e]	243[e]	0[e]	261	4	217	2	234	11	236	17
P1-1.00	252	12	260	4	314	2	246	13	288	6	272	28
P2-0.00	275	2	257	3	308	3	274	7	292	5	281	19
P2-0.50	290	4	260	3	324	1	229	6	304	5	293	23
P2-1.00	292	2	282	4	354	1	290	5	304	0	304	29
P3-0.00	284	2	256	3	346	2	295	2	330	5	302	36
P3-0.25	254	12	235	5	308	2	-	-	326	4	281	43
P3-0.50	193	16	179	8	218	8	265	7	267	7	224	41
P3-0.75	152	11	170	6	200	6	182	15	196	10	180	20
P3-1.00	165	7	180	3	199	5	179	7	200	5	185	15
P4-0.00	167	5	170	3	172	5	186	5	184	4	176	9
P4-0.25	184	1	189	4	176	6	186	1	205	6	188	11
P4-0.50	223	1	222	7	195	6	207	3	234	6	216	15
P4-1.00	262	2	263	3	257	4	246	4	246	1	258	7
SE	233	2	250	11	199	11	282	2	286	1	250	36

a All units are in millivolts.

b Locations are described as in the example:
SI refers to the secondary influent
P3-0.75 refers to a position which is three quarters of the pass length (3/4 x 320 ft. = 240 ft.) as measured from the start of the third pass.
SE refers to the secondary effluent.

c E_h represents the average ORP of the readings.

d s represents the standard deviation of the readings.

e These values are the average readings for 3 electrodes; all other values are the average readings for 4 electrodes.

f This is the standard deviation of average ORP readings for Tanks 1 to 5.

TABLE D2: ORP PROFILE DATA FOR AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - VARIOUS OPERATIONS

Location[b]	Step Aeration - 22/03/73 p.m.		Step Aeration - 23/03/73 p.m.		Increased Hydraulic Load 27/03/73 p.m.		Increased Hydraulic Load 28/03/73 a.m.		Normal - 03/04/73 p.m.		Reduced Aeration 05/04/73 a.m.		Reduced Aeration 06/04/74 p.m.		Increased Suspended 19/04/73 p.m.		Increased Suspended 24/04/73 a.m.	
	E_h[c]	s[d]	E_h	s	E_h	s	E_h	s	E_h	s	E_h	s	E_h	s	E_h	s	E_h	s
SI	90	14	72	9	22	10	19[e]	14	22	9	24[e]	9[e]	48[e]	6[e]	66	11		
P1-0.00	181	11	208	6	200[e]	3[e]	211	5	215	1	114[e]	10e	95[e]	8[e]	224	13	164	11
P1-0.50	208	13	239[e]	3[e]	230[e]	3[e]	233	2	261	4	103[e]	12[e]	138[e]	5[e]	264	13	170	9
P1-1.00	207	14	225[e]	2[e]	240	10	257	2	314	2	112[e]	12[e]	135[e]	2[e]	281	12	220	5
P2-0.00	164	13	170	5	213[e]	2	242[e]	0	308	3	115[e]	12[e]	134[e]	2[e]	278	11	214	8
P2-0.25	162	15	169	10	184[e]	2[e]	221[e]	2[e]	-	-	-	-	-	-	-	-	-	-
P2-0.50	159	15	160[e]	7[e]	176[e]	13	215[e]	1[e]	324	1	102[e]	11[e]	145[e]	2[e]	282	9	239	3
P2-0.75	181	13	177[e]	4[e]	179[e]	7[e]	215	2[e]	-	-	-	-	-	-	-	-	-	-
P2-1.00	205	19	209	4	202[e]	5[e]	245	1	354	1	144[e]	10[e]	165[e]	1[e]	308	11	258	4
P3-0.00	183	15	203	1	195	6	234[e]	0[e]	346	2	122[e]	12[e]	145[e]	1[e]	299	10	249	4
P3-0.25	187	14	188	3	184[e]	8[e]	215e	0[e]	308	2	136[e]	12[e]	-	-	284	7	239	6
P3-0.50	176	15	181	3	183[e]	6[e]	204[e]	1[e]	218	8	121[e]	12[e]	105[e]	3[e]	212	15	198	8
P3-0.75	176	13	194	6	186[e]	8[3]	215	1	200	6	124[e]	10[e]	115[e]	1[e]	176	12	167	5
P301.00	172	11	195	2	184	3	204	1	199	5	117[e]	9[e]	117[e]	1[e]	168	12	158	7
P4-0.00	191	15	196	4	180	5	199	5	172	5	124[e]	11[e]	123[e]	0e	150	13	175	7
P4-0.25	223	10	-	-	229	6	248	2	176	6	135[e]	11[e]	-	-	171	10	224	2
P4-0.50	244	13	248	4	254	6	271	1	195	6	142[e]	9[e]	126	1	190	13	259	3
P4-1.00	260	11	273	5	276	6	287	2	257	4	154[e]	11	151[e]	2[e]	278	11	280	5
SE	253	11	298	5	284	4	291	2	199	11	146[e]	7[e]	110[e]	7[e]	290	7	273	1

[a] All units are in millivolts.

[b] Locations are described as in the example:
SI refers to the secondary influent.
P3-0.75 refers to a position which is three qurters of the pass length (3/4 x 320 ft. = 240 ft.) as measured from the start of the third pass.
SE refers to the secondary effluent.

[c] E_h represents the average ORP of the readings.

[d] s represents the standard deviation of the readings.

[e] These valuse are the average readings for 3 electrodes; all other values are the average readings for 4 electrodes.

TABLE D3: DISSOLVED OXYGEN DATA FOR AERATION TANKS 1 TO 5, EDMONTON SEWAGE TREATMENT PLANT FEBRUARY 20, 1973

	Aeration Tank					
Location[a]	1	2	3	4	5	Average
P1-0.00	0.50	0.60	0.70	0.60	0.30	0.55
P1-0.25	0.50	0.60	0.40	0.70	0.40	0.50
P1-0.50	0.50	0.70	0.40	0.70	0.40	0.55
P1-0.75	0.50	0.60	0.50	0.90	0.40	0.60
P2-0.25	0.40	0.50	0.65	1.05	0.70	0.65
P2-0.50	0.40	0.60	0.55	1.60	1.10	0.65
P2-0.75	0.40	0.50	0.60	2.10	1.30	1.00
P3-0.25	0.90	0.70	0.80	1.10	1.70	1.05
P3-0.50	0.80	0.70	0.60	0.80	1.40	0.85
P3-0.75	0.60	0.70	0.60	0.60	0.20	0.55
P4-0.25	0.95	0.80	0.70	0.60	0.70	0.75
P4-0.50	1.60	1.10	0.85	0.80	0.70	1.00
P4-0.75	2.30	1.50	1.10	1.20	1.20	1.45

[a] Locations referred to are as in the example:

<u>Location P3 - 0.75</u>

P3 refers to Pass 3
0.75 refers to a point which is three quarters of the pass length from the start of the particular pass.

TABLE D4: ORP AND DO PROFILE DATA FOR AERATION TANK 3
EDMONTON SEWAGE TREATMENT PLANT

Location[a]	March 12[b]		March 14[b]		March 27[b]		April 19[b]	
	ORP mv.	DO mg./l.	ORP mv.	DO mg./l.	ORP mv.	DO mg./l.	ORP mv.	DO mg./l.
P1-0.00	392	1.10	349	0.90	200	0.50	224	0.50
P1-0.25		1.70		1.05		0.50		0.50
P1-0.50	419	4.80	376	2.90	230	0.55	264	0.60
P1-0.75		6.20		5.05		0.50		0.75
P1-1.00	425	9.20	389	5.80	240	0.55	281	1.00
P2-0.00					213		278	
P2-0.25		5.05		4.35	184	0.40		0.95
P2-0.50	389	3.80	362	3.30	176	0.40	282	0.90
P2-0.75		6.40		4.80	179	0.40		0.80
P2-1.00	397	6.80	379	7.25	202	0.55	308	0.80
P3-0.00	371		378	7.00	195	0.50	299	
P3-0.25	319	0.40	371	4.80	184	0.35	284	0.85
P3-0.50	282	0.40	323	1.05	183	0.30	212	0.70
P3-0.75	250	0.40	305	0.90	186	1.05	176	0.80
P3-1.00	246	0.60	298	0.85	184	1.05	168	0.85
P4-0.00					180		150	
P4-0.25	289	1.20	296	4.20	229	1.80	171	0.90
P4-0.50	300	2.45	317	6.25	254	3.20	190	0.90
P4-0.75		2.85		7.65		4.60		1.30
P4-1.00	321	3.10	339	8.85	276	6.15	278	2.90

[a] Locations referred to are as in the example:

Location P3 - 0.75

P3 refers to Pass 3
0.75 refers to a point which is three quarters of the pass length from the start of the particular pass.

[b] Supplementary data is contained in TABLE E2

APPENDIX E

OPERATIONAL DATA FOR THE AERATION TANKS AT THE EDMONTON SEWAGE TREATMENT PLANT

TABLE E1: AVERAGE MONTHLY DATA FOR AERATION TANKS 1, 2, 4 AND 5, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION (JANUARY TO APRIL, 1973)[a]

Month	Aeration Tank	Secondary Influent			Return Sludge		Waste Sludge[b]	Mixed Liquor	Secondary Effluent	
		Q MIGD	BOD mg./l.	SS mg./l.	Q MIGD	SS mg./l.	Q MIGD	SS mg./l.	BOD mg./l.	SS mg./l.
Jan.	1	7.1	167	116	2.0	4470	0.14	1170	30	47
	2	7.1	167	116	2.0	4270	0.14	1060	33	55
	4	7.1	167	116	2.0	3470	0.13	920	33	48
	5	7.1	167	116	2.0	3400	0.13	1100	33	49
	Avg.	7.1	167	116	2.0	3900	0.14	1060	33	50
Feb.	1	7.1	154	148	2.0	4630	0.21	1300	22	39
	2	7.1	154	148	2.0	4840	0.21	1260	24	40
	4	7.1	154	148	2.0	3930	0.11	990	28	45
	5	7.1	154	148	2.0	4040	0.12	1380	22	40
	Avg.	7.1	154	148	2.0	4360	0.16	1230	24	41
Mar.	1	8.0	130	207	1.9	6240	0.21	1560	23	45
	2	8.0	130	207	1.9	5500	0.30	1330	26	49
	4	8.0	130	207	1.9	5200	0.16	1270	30	47
	5	8.0	130	207	1.9	5520	0.20	1680	25	41
	Avg.	8.0	130	207	1.9	5610	0.22	1460	26	46
Apr.	1	8.1	128	174	2.0	4740	0.21	1210	27	39
	2	8.1	128	174	2.0	4870	0.19	1200	29	40
	4	8.1	128	174	2.0	3680	0.16	960	33	41
	5	8.1	128	174	2.0	4150	0.18	1340	31	38
	Avg.	8.1	128	174	2.0	4360	0.18	1180	30	40

a All BOD and SS data is the average for 24-hour composite samples taken at one-hour intervals. Flow rate data is the daily average.

b SS for waste sludge = RSSS

TABLE E2: DATA FOR AERATION TANK 3, EDMONTON SEWAGE TREATMENT PLANT - VARIOUS OPERATIONS (MARCH TO APRIL, 1973)[a]

Operating Condition	Date	Secondary Influent Q MIGD	Secondary Influent BOD mg./l.	Secondary Influent SS mg./l.	Return Sludge Q MIGD	Return Sludge SS mg./l.	Waste[b] Sludge Q MIGD	Mixed Liquor SS mg./l.	Secondary Effluent BOD mg./l.	Secondary Effluent SS mg./l.	Total Aeration Rate[c] MCFD
Step Aeration	Mar.12	6.4	114	205	1.9	6200	0.19	1790	24	23	16.5[d]
	14	7.9	130	220	1.9	6250	0.19	1620	29	34	16.1
	22	8.8	122	271	2.0	7250	0.25	1710	18	45	10.0
	23	8.5	138	214	1.9	7950	0.25	1720	21	49	10.5
	24	8.8	113	200	2.0	6860	0.25	1560	23	56	-
	25	8.5	116	189	1.9	6390	0.24	1490	18	34	-
Increased hydraulic load	27	12.3	127	197	2.7	6490	0.25	1680	21	62	14.5
	28	11.7	140	180	2.9	6690	0.25	1650	15	32	12.7
	29	11.8	144	163	2.9	6320	0.25	1530	16	33	-
	30	12.0	140	144	2.9	6160	0.27	1500	17	23	-
Normal	Apr. 2	6.8	97	105	2.0	3950	0.20	1280	29	41	-
	3	8.0	156	156	2.0	4170	0.20	1030	43	72	13.0
Reduced Aeration	Apr. 5	7.8	139	187	2.0	4200	0.20	1120	35	64	6.3
	6	7.7	134	172	2.0	4020	0.27	1030	48	72	11.0
Increased suspended solids	Apr.18	8.4	151	202	4.0	11440	0.35	3600	17	24	-
	19	8.4	122	145	3.5	10000	0.20	3160	13	32	14.0
	20	9.0	129	299	3.5	9890	0.20	3200	13	20	-
	21	7.5	88	121	3.5	8580	0.20	3070	14	22	-
	22	7.4	77	109	3.5	7870	0.20	2660	13	18	-
	23	7.0	93	129	3.5	7330	0.20	2760	16	16	-
	24	8.6	183	215	3.5	8920	0.01	2560	20	24	13.0
	25	8.5	163	143	3.5	9790	0.00	3080	20	26	-
	26	7.9	148	129	3.5	11580	0.10	3220	12	24	-
	27	8.3	140	133	3.5	9740	0.10	2950	19	20	-

[a] All BOD and SS data is the average for 24-hour composite samples taken at one-hour intervals. Flow rate data is the daily average.

[b] SS for waste sludge = RSSS

[c] Aeration rates are the average rates observed during profile measurements and are uniform throughout tanks unless otherwise stated.

[d] 65% of total air flow was for Passes 1 and 2.

35% of total air flow was for Passes 3 and 4.

TABLE E3: AVERAGE DATA FOR AERATION TANKS 1, 2, 4, AND 5, EDMONTON SEWAGE TREATMENT PLANT - NORMAL OPERATION (MARCH TO APRIL, 1973)[a]

	Secondary Influent			Return Sludge		Waste[b] Sludge	Mixed Liquor	Secondary Effluent		Total Aeration Rate[c]
Date	Q MIGD	BOD mg./l.	SS mg./l.	Q MIGD	SS mg./l.	Q MIGD	SS mg./l.	BOD mg./l.	SS mg./l.	MCFD
Mar.12	6.4	114	205	1.9	5430	0.40	1550	33	34	12.0
14	8.2	130	220	1.9	5750	0.40	1400	28	33	16.1
Mar.22	8.8	122	271	2.0	6410	0.26	1610	20	50	10.0
23	8.5	138	214	1.9	6560	0.26	1680	22	50	10.5
24	8.8	113	200	2.0	6060	0.27	1520	18	44	-
25	8.5	116	189	1.9	5760	0.25	1480	25	39	-
Mar.27	7.9	127	197	2.0	5580	0.26	1530	25	67	10.3
28	6.9	140	180	2.0	5450	0.26	1480	18	52	9.0
29	7.6	144	163	1.9	5300	0.26	1370	22	28	-
30	7.7	140	144	1.9	4670	0.28	1320	20	32	-
Apr. 2	6.8	97	105	2.0	4220	0.21	1390	26	35	-
3	8.0	156	156	2.0	4000	0.20	1030	38	52	14.3
Apr. 5	7.8	139	187	2.0	4210	0.19	1220	23	54	8.4
6	7.7	134	172	2.0	4100	0.21	1180	24	43	14.0
Apr.18	8.4	151	202	2.0	5140	0.24	1230	21	35	-
19	8.4	122	145	2.0	4760	0.24	1550	32	43	12.0
20	9.0	129	299	2.0	5240	0.24	1330	26	40	-
21	7.5	88	121	2.0	4720	0.24	1260	24	28	-
22	7.4	77	109	2.0	4190	0.24	1120	-	31	-
23	7.0	93	129	2.0	3840	0.24	1160	34	26	-
24	8.6	183	215	2.0	3680	0.24	980	44	51	8.0
25	8.5	163	143	2.0	3520	0.24	1020	43	52	-
26	7.9	148	129	2.0	4200	0.09	1110	36	55	-
27	8.3	140	133	2.0	4180	0.10	1080	46	45	-

[a] All BOD and SS data is the average for 24-hour composite samples taken at one-hour intervals. Flow rate data is the daily average.

[b] SS for waste sludge = RSSS

[c] Aeration rates are the average rates observed during profile measurements and are uniform throughout tanks unless otherwise stated.